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Building a More Resilient and Low-Carbon Caribbean

Report 5 - Decarbonization Pathways for the Caribbean Construction Industry

Jed Bailey
Livia Minoja
Alexandra Alvear
Christiaan Gischler

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Social Infrastructure

Building a More Resilient and Low-Carbon Caribbean

REPORT 5

Decarbonization Pathways for the Caribbean Construction Industry

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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. According to the Emergency Events Database (EM-DAT)[1], countries within the Caribbean (not including Puerto Rico) endured 101 natural disasters in the decade from 2013-2022[2]. Of those with available data, each country-level natural disaster event, on average, affected 367,000 people, including 66 deaths, 1,040 injured, and 3,400 made homeless. Average damages were reported to be US$853 million (2022 dollars). In 2017, Hurricane Irma caused US$13.3 billion in damages across fourteen countries in the region. In 2019, Hurricane Dorian caused US$3.9 billion in damages in the Bahamas alone.

Within this context of high vulnerability and worsening Climate Change (CC) impacts, building sustainability and resiliency is critical to prioritize 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 is the result of a close collaboration between the IDB Social Infrastructure Group (GIS)and the IDB Energy Division (ENE).

1 EM-DAT is maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the Université catholique de Louvain (UCLouvain)

2 Puerto Rico was excluded owing to the dramatic skewing of the data from Hurricane Maria in 2017, in which damages were reported to be US$81 billion).

The first four reports of the series[3] analyze the economic losses caused by climate related events, the benefits of improving building resiliency to reduce those economic losses, the benefits of subsidized financing for resilient buildings, and the potential for nature-based solutions (NBS) in the Caribbean. The results show that increasing building resiliency is economically viable for Caribbean islands at high-risk from natural disasters, generating long term savings and increasing the infrastructure preparedness to the impacts of CC. In addition, NBS can simultaneously reduce the region's vulnerability to climate change and the carbon emissions embodied in its infrastructure.

This report – Report 5: Decarbonization Pathways for the Caribbean Construction Industry - extends the previous analysis to examine potential options to reduce embodied carbon in traditional resilient building materials such as cement and steel in the region. The report first examines the source of cement and steel in the Caribbean construction industry. It then considers the carbon emissions related to the supply of these materials to the region. Next, the report reviews potential alternatives to reduce the carbon footprint of these materials. This analysis includes adjusting supply chains to prioritize imports from lower-carbon sources, using lower-carbon versions of the materials, and reducing the overall volume of materials used in construction through alternative designs. Next, the report analyzes the potential reduction in embodied carbon in resilient construction through a case study focused on an example residential building. Next, the report suggests incentives that can be applied to promote the reduction of carbon emissions from construction in the Caribbean. Finally, the report suggests potential demonstration projects to test the viability of the most promising suggested options.

3 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
Report 4: Infrastructure Resilience in the Caribbean through Nature Based Solutions

This publication was made possible thanks to the valuable contributions and revisions from Pauline Henriquez Leblanc (IFD/CTI), Adrian Vogt-Schilb (CSD/CCS) and Roberto Aiello (INE/ENE).

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1. Executive Summary

Cement and steel are among the most important resilient building materials in the Caribbean, but also require large amounts of energy to produce with correspondingly high levels of embodied carbon. This report examines potential options to reduce the embodied carbon from the use of these materials in the region. Reducing the embodied carbon emissions in construction materials without sacrificing resiliency to climate hazards will benefit countries in the Caribbean.

The analysis finds that the majority of the cement used in the Caribbean is sourced from within the region. Nine countries within the Caribbean produce cement: Barbados, Guadeloupe, Haiti, Jamaica, Martinique, Puerto Rico (USA), Dominican Republic, Suriname, and Trinidad and Tobago. These countries provide the majority of the cement supplied to Caribbean countries that do not produce cement. By contrast, steel used in construction is largely sourced from outside the region. Trinidad and Tobago is the only country in the region with a history of significant steel exports. In addition, steel imports to the Caribbean are sourced from many countries, including as far away as China, Turkey, Brazil, and Canada.

The embodied carbon emissions related to the supply of cement and steel to the Caribbean include carbon emissions from the production of the material as well as the carbon emissions resulting from shipping the material from the country of origin to the Caribbean region. The analysis found that the embodied carbon emissions from the top eight sources of cement in the Caribbean ranged between 614 kg of CO2 per tonne (Dominican Republic) to 941 kg of CO2 per tonne (Turkey), with a weighted average for the region of 830 kg of CO2 per tonne. Embodied carbon from shipping cement from the source country to the region was found to account for 54 kg of CO2 per tonne of cement shipped, or 7% of the total embodied carbon for imported cement on average. This reflects the very small role of shipping emissions in the total embodied emissions for cement. The embodied carbon emissions from the top nine sources of steel in the Caribbean ranged between 864 kg of CO2 per tonne (Trinidad and Tobago) to 2,214 kg of CO2 per tonne (China), with a weighted average for the Caribbean region of 1,421 kg of CO2 per tonne. Embodied carbon from shipping steel from the source country to the region was found to account for 132 kg of CO2 per tonne, or 9% of the total embodied carbon for imported steel on average.

The study explored three broad options to reduce the embodied carbon in cement and steel in the Caribbean: prioritizing the least carbon intensive sources for cement and steel (that is, shifting supply chains to source cement and steel from producers with the lowest carbon intensity), substituting traditional cement and steel with less carbon intensive alternatives, and reducing the volume of cement and steel used per building through alternative designs and elements.

Changing supply chains so that all cement used in the region was sourced from the country with the lowest embodied carbon was found to reduce embodied carbon by a quarter. A similar shift for steel would reduce the embodied carbon by one-third (if it were able to be sourced from Trinidad and Tobago) or a quarter (if from the United States). Such a shift, however, could be limited by the source countries' ability to produce sufficient materials, logistical constraints, and by contractual and trade relationships among suppliers. Shifting to the sources with the lowest embodied carbon could also increase the cost of cement and steel imports as current trade arrangements likely reflect a preference to source materials from the least-cost suppliers.

Substituting traditional materials with less carbon intensive alternatives was limited to alternatives for traditional cement, as low-carbon steel is not yet commercially available. Options to reduce the embodied carbon in concrete included green cement and concrete blends with reduced cement content. Green cement—that is, cement with reduced embodied carbon that is manufactured with reduced clinker content using alternative binding chemistries or manufactured with carbon-neutral fuels—is currently available and produced in the Caribbean. Green cement in the Caribbean has at least 25% less embodied carbon as regular cement and can reduce embodied carbon by up to 70%. Alternative concrete blends include using ground granulated blast-furnace slag (GGBS, a waste product from steel manufacturing) and pulverized fuel ash (PFA, a byproduct from burning coal for power generation), as well as recycled plastics and other waste materials. These options reduced the embodied carbon in the resulting concrete by a quarter. There are no blast furnaces in the Caribbean. Therefore, implementing GGBS concrete in the region would require importing the slag material. There are, however, coal fired power plants, including large-scale plants in the Dominican Republic and Puerto Rico, which could provide ash waste for PFA concrete. In addition, the Caribbean produces plastic wastes that could be suitable for use in concrete. Doing so would require new facilities to separate the plastics from the general waste stream and prepare it for use. Such facilities would prepare the recycled resins at high enough temperatures to avoid the release of other environmental contaminants such as dioxins and furans from the plastics.

The volume of cement used per building can also be reduced through alternative designs and materials for key elements such as the floor slab, roof, outer walls and inner walls. For example, in-situ reinforced concrete slabs used for residential building floors and roofs can be replaced with waffle or trough slabs, which reduce the volume of concrete by creating void spaces when the slab is poured. These designs also require less steel reinforcement than standard concrete slabs. Other options include prefabricated modules such as double tees or hollow core units that are manufactured at a central facility and then transported to the construction site.

Solid bricks used in the inner and outer walls of residential buildings call also be substituted with materials with less embodied carbon. Inner walls can built with less resilient materials, such as plasterboard on timber framing, as the inner walls do not contribute to the building's ability to withstand natural hazards. Outer walls built with concrete blocks also have less embodied carbon than standard bricks. Concrete block options include medium weight hollow blocks, autoclaved aerated blocks, and cellular blocks.

The study built upon these findings to quantify the cumulative benefits from applying multiple methods of reducing the embodied carbon emissions within a single building. That is, it calculated the total potential reduction in embodied carbon from using alternative designs, built with low-carbon materials, sourced from countries with the lowest average carbon content. The analysis used the World Bank Excellence in Design for Greater Efficiencies (EDGE) software and database and the Inventory of Carbon and Energy (ICE) database to examine the potential reductions in embodied carbon emissions for a standard low income house in Dominica.

In the EDGE software, the default materials for the house are a standard in-situ reinforced concrete slab for the floor and walls and solid brick with plaster on both sides for the inner and outer walls. Using these materials, a 60 m^2 house was calculated to have 22.4 metric tonnes of embodied carbon emissions.

Substituting in-situ filler slabs for the floor and roof, cellular concrete blocks for the outer walls, and plasterboard on timber studs for the inner walls reduces the embodied carbon emissions in the building to 7.7 metric tonnes, a 66% reduction from the default materials. Using cement and steel sourced

m the countries with the lowest average embodied carbon emissions reduces the building's embodied carbon emissions to 5.8 metric tonnes, a 74% reduction from the default materials. Using green cement (with 20% less embodied carbon than standard cement) further reduces the building's embodied carbon emissions to 5.2 metric tonnes, a 77% reduction from the default materials.

This analysis suggests that the embodied carbon in resilient buildings can be significantly reduced through changes in building materials and design. Simply using cellular concrete blocks for the outer walls and plasterboard on timber studs for the inner walls reduced the building's embodied carbon by 37%. Using designs that require less steel rebar, such as the in-situ filler slab for the floor and roof, also had a significant impact on the building's total embodied carbon.

The analysis also highlighted the high embodied carbon in steel and standard bricks. Steel and bricks accounted for 86% of the embodied carbon in the house built with default materials. Efforts to reduce the building's embodied carbon emissions that only focused on its concrete components would be relatively ineffective. For example, using green cement without changing the use of steel and bricks would have reduced the original building's total embodied carbon by just 3%, or 0.6 metric tons.

Policy interventions to incentivize the implementation of these changes include measures that affect cement demand as well as supply. Possible demand-side measures include requiring the use of concrete block outer walls and plasterboard on timber studs inner walls in government-sponsored construction or for all new residential construction through changes in the building code, promoting green cement to increase consumer and developer awareness of its availability and potential benefits, subsidizing the use of green cement, and mandating the use of green cement in government-sponsored construction or for all new construction, and mandating maximum embodied carbon limits per square meter for buildings. Supply-side measures include promoting best practices and cross-industry learning, mandating embodied carbon targets for cement and concrete production, and applying a carbon-based VAT tax to cement and concrete.

Implementing the proposed decarbonization measures will require social acceptance by developers, contractors, and building owners. This will take time and government budgetary support, as well as regulatory and, potentially, legislative changes. Ideally, any measures that are implemented should be aligned and incorporated into a country's climate change plans, including their nationally determined contributions (NDCs) under the Paris Agreement. This will help ensure they are coordinated and complementary to other government efforts to reduce carbon emissions across the country's economy.

Pilot projects that are limited in scope can test the assumptions behind the proposed interventions before they are applied at scale. For example, building a demonstration house using the identified lowest embodied carbon design and material options would highlight any barriers or unforeseen challenges to implementing the proposed materials and designs in the Caribbean. Once completed, the model home could also serve as a public relations and public education tool, allowing visitors to learn more about how the building was built, the challenge of embodied carbon in buildings, the benefits from reducing the amount of embodied carbon in resilient buildings, and other benefits to the homeowner, such as reduced weight and improved thermal insulation from concrete made with plastic resin and other alternative aggregate materials.

A pilot procurement process for a government building contract using the identified designs and materials would provide policy makers, government officials, and construction companies experience in developing, implementing, and evaluating requests for proposal (RFP) processes that include lower embodied carbon requirements. The learnings from this pilot process could then be shared across the region to help other countries implementing their own processes.

In addition, regional conferences could convene government, financial institution, industry, and NGO leaders from across the Caribbean and beyond to share their insights on the benefits of reducing the embodied carbon within buildings, as well as the challenges to implementing low carbon construction in the region. These events would combine expertise in the regional conditions facing the Caribbean with global expertise in green construction materials and methods to find workable solutions for the region.

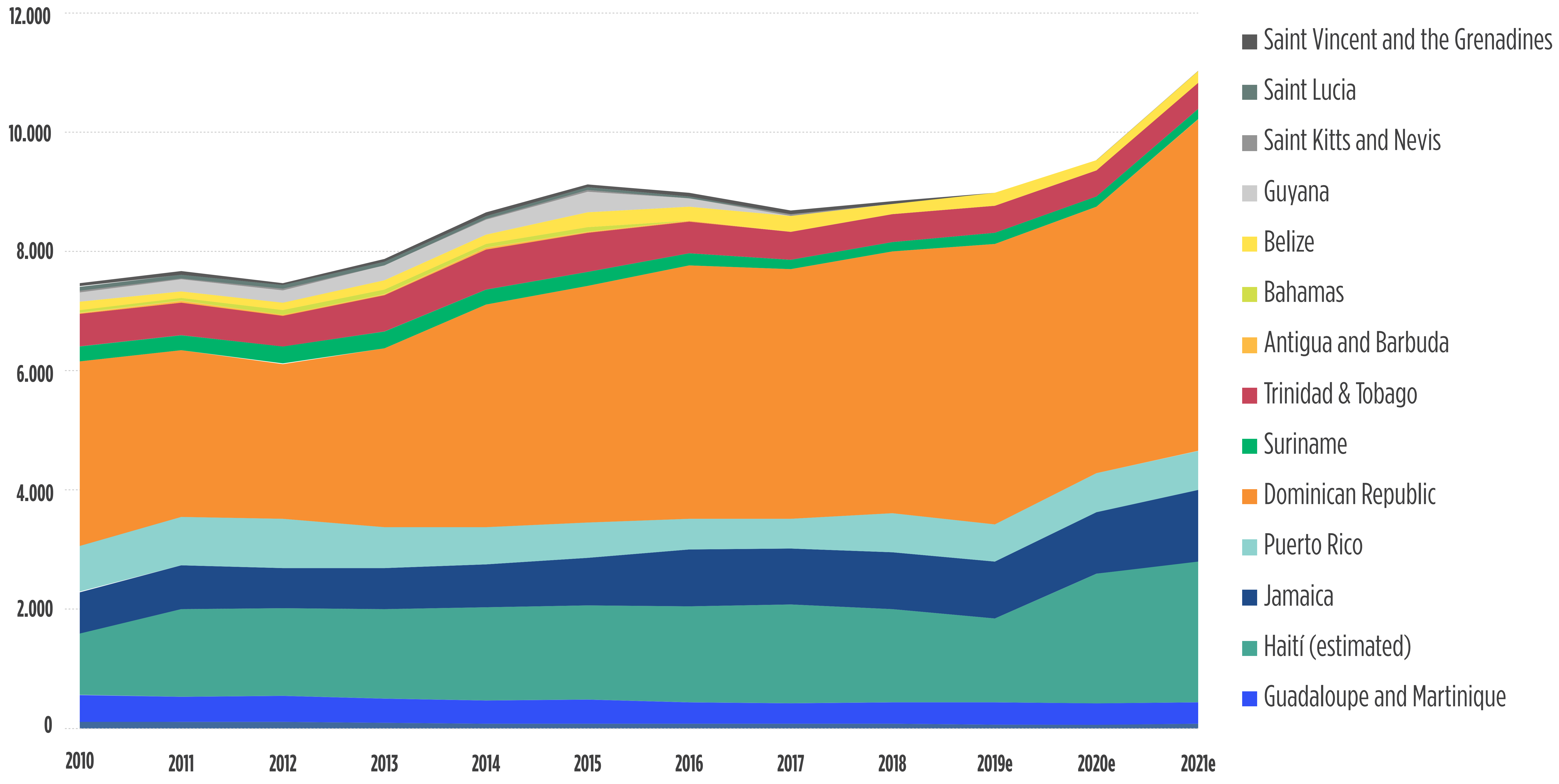
2. Cement and Steel Supply Chains in the Caribbean

This section analyzes the cement and steel supply chains in the Caribbean using data from the Inter-American Cement Federation (FICEM) and the United Nations Comtrade database. The section first presents data on cement production, consumption, and trade in the region (Section 2.1). It then presents data on steel imports and exports in the region (Section 2.2).

2.1 Cement

Cement is one of the most important building materials used in the Caribbean, owing to its strong resilience to natural hazards, long lifespan, and relatively low cost. It is a key ingredient in concrete, along with sand and aggregate. Cement is also locally produced in several Caribbean countries. In addition to these benefits, however, cement production requires large amounts of energy, resulting in high levels of embodied carbon in both cement and the resulting concrete in which it is used. This section reviews the historical demand for cement in the Caribbean (Section 2.1.1), the region's sources of supply (Section 2.1.2), and the overall supply-demand balances and trade (Section 2.1.3).

Figure 2.1: Caribbean cement demand for select countries



Source: FICEM

2.1.1 Cement Demand

Table 2.1 and Figure 2.1 shows the reported demand for cement from 2010 to 2021, divided among countries that produce cement and those that do not.

Overall, cement demand from this group of countries increased 4.6% per year between 2010 and 2015[4], growing from 7.46 million tonnes per annum (mtpa) to 9.13 mtpa. This growth, however, is almost entirely driven by the Dominican Republic (accounting for 44% of the total market), where cement consumption increased from 3.1 mtpa in 2010 to 3.97 mtpa in 2015 (5.6% per year on average) and Haiti, which increased from 1.04 mtpa to 1.58 mtpa (10.5% per year on average) in the same period.

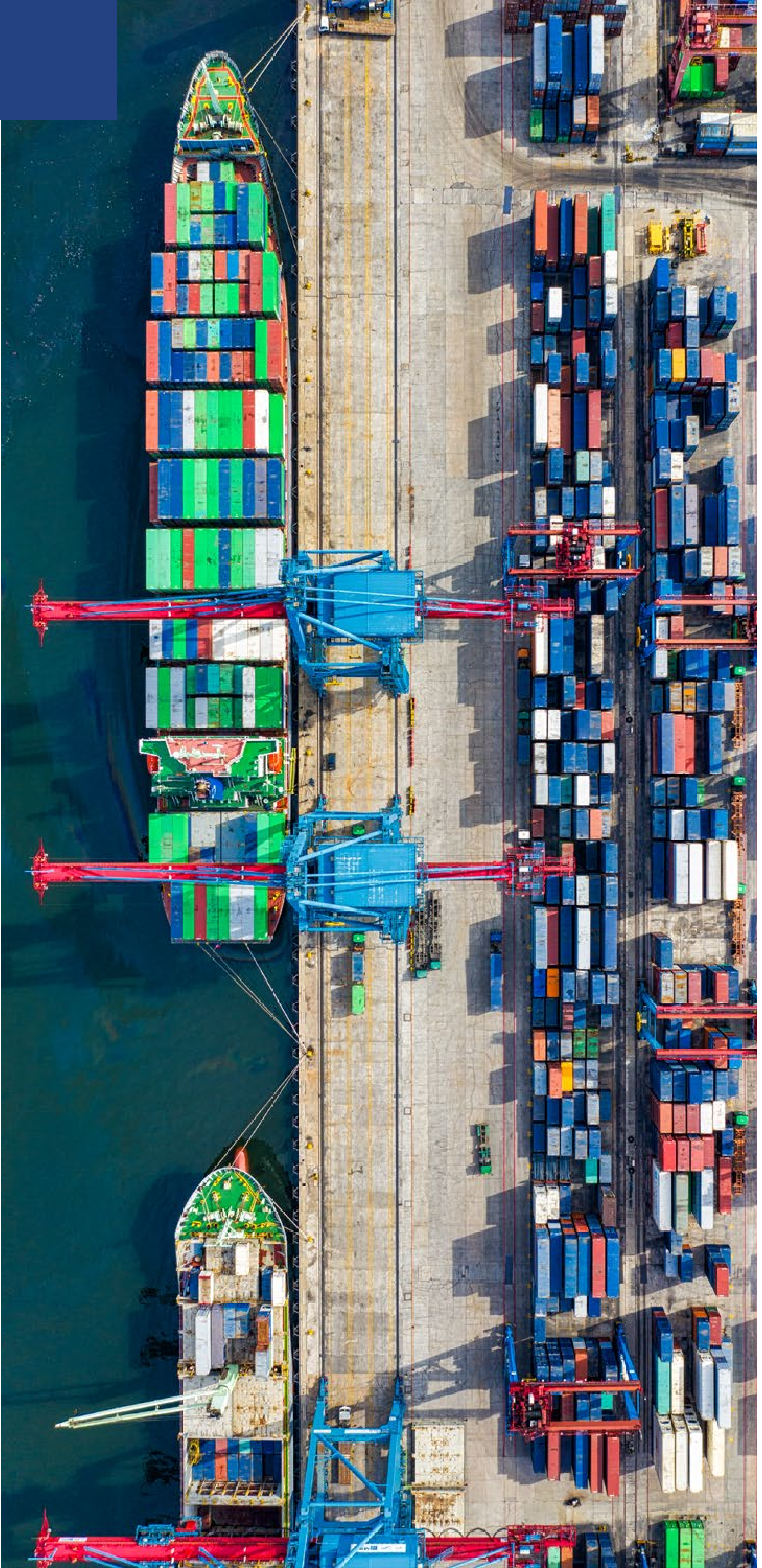
4 2015 is the most recent year with data for all countries in the group

Table 2.1: Caribbean cement demand for select countries (thousand metric tonnes per year)

Country	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019e	2020e	2021e
Barbados	112	103	98	84	81	80	75	71	68	61	56	67
Guadaloupe and Martinique	440	432	438	406	389	394	362	349	359	371	355	373
Haití (estimated)	1.037	1.468	1.474	1.505	1.550	1.581	1.612	1.661	1.565	1.406	2.180	2.360
Jamaica	696	724	670	689	728	808	950	927	953	950	1.035	1.192
Puerto Rico	771	811	834	682	620	580	520	510	664	630	659	658
Dominican Republic	3.100	2.800	2.600	3.000	3.740	3.970	4.247	4.183	4.390	4.703	4.467	5.567
Suriname	250	260	290	280	250	239	203	156	154	184	168	175
Trinidad & Tobago	548	535	512	618	666	656	526	461	466	454	436	441
Total - Producing Countries	**6.954**	**7.133**	**6.916**	**7.264**	**8.024**	**8.308**	**8.495**	**8.318**	**8.619**	**8.759**	**9.356**	**10.833**
Antigua and Barbuda	5	34	23	19	30	25	20	n/a	n/a	n/a	n/a	n/a
Bahamas	51	54	73	76	69	76	n/a	n/a	n/a	n/a	n/a	n/a
Belize	150	100	120	150	160	250	240	280	181	230	180	200
Guyana	153	204	216	246	243	341	125	n/a	n/a	n/a	n/a	n/a
Saint Kitts and Nevis	27	23	23	13	18	35	n/a	29	n/a	n/a	n/a	n/a
Saint Lucia	70	62	71	52	45	46	44	n/a	n/a	n/a	n/a	n/a
Saint Vincent and the Grenadines	51	55	17	52	59	49	51	57	46	n/a	n/a	n/a
Total Non-Producing Countries	**508**	**533**	**542**	**609**	**624**	**821**	**480**	**366**	**227**	n/a	n/a	n/a
Caribbean Total	**7.462**	**7.666**	**7.458**	**7.873**	**8.648**	**9.129**	**8.976**	**8.684**	**8.846**	**8.759**	**9.356**	**10.833**

Source: FICEM

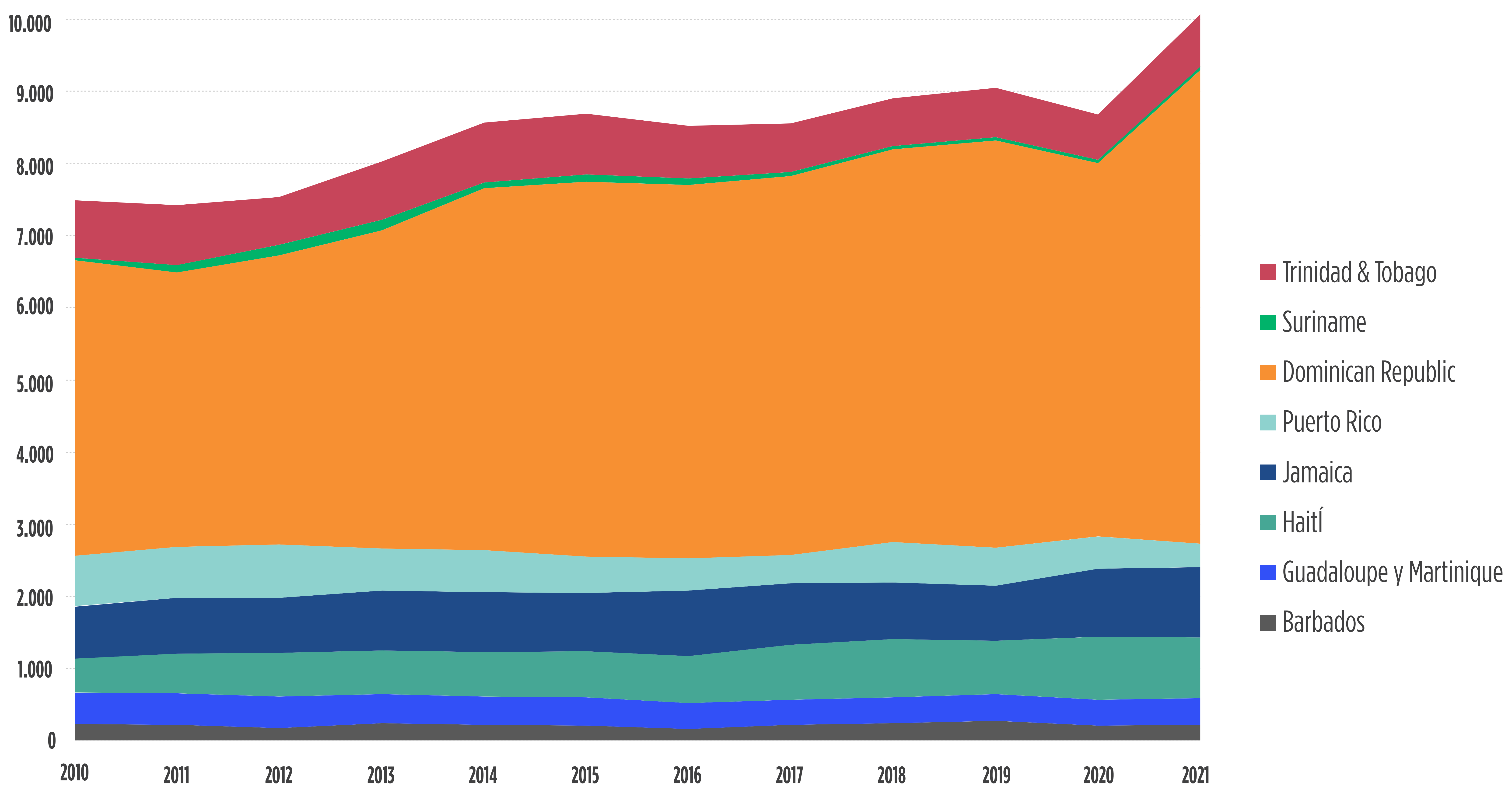
All other countries added a net 0.29 mtpa in incremental cement demand in the period, with seven countries posting demand growth (Jamaica, Trinidad & Tobago, Antigua & Barbuda, Bahamas, Belize, Guyana, and St. Kitts & Nevis), six showing shrinking cement consumption (Barbados, Guadeloupe, Martinique, Puerto Rico, St. Lucia, and St. Vincent and the Grenadines), and Suriname remaining flat.



2.1.2 Supply

Cement is produced in eight countries in the region. Annual cement production data provided by FICEM is shown in Table 2.2 and Figure 2.2 below.

Figure 2.2: Caribbean cement production (thousand metric tonnes per year)



Source: FICEM

The Dominican Republic is by far the largest regional producer of cement, accounting for more than half of the regional total, and is also the main cement exporter in the region. This is driven by the Dominican Republic's relatively large population (at just over 11 million people, it has a similar number of inhabitants as Haiti and Cuba, and is roughly four times the size of the fourth most populous island, Puerto Rico). Information on Cuba's cement production was unavailable, while Haiti and Puerto Rico are also major cement producers, but consume most of their production domestically.

Total cement production in the region has increased by 2.58 million tonnes per year, or by 34% over 2010 levels. Almost all of this increase has come from the Dominican Republic, which increased production by 2.46 million tonnes per year in that period.

Table 2.2: Caribbean cement production (thousand metric tonnes per year)

Country	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Barbados	229	223	176	243	220	208	160	216	238	272	208	216
Guadaloupe y Martinique	441	431	438	406	389	394	362	349	359	371	355	373
HaitÍ	468	554	604	602	620	632	645	768	807	742	880	840
Jamaica	723	766	760	825	830	808	908	846	788	759	940	979
Puerto Rico	697	717	743	590	580	514	450	390	564	526	450	320
Dominican Republic	4.100	3.800	4.000	4.400	5.018	5.181	5.171	5.254	5.430	5.640	5.169	6.562
Suriname	30	100	150	150	70	102	97	53	46	52	44	50
Trinidad & Tobago	791	827	654	802	837	840	721	670	665	678	632	723
Total	**7.479**	**7.418**	**7.525**	**8.018**	**8.564**	**8.679**	**8.514**	**8.546**	**8.897**	**9.040**	**8.678**	**10.063**

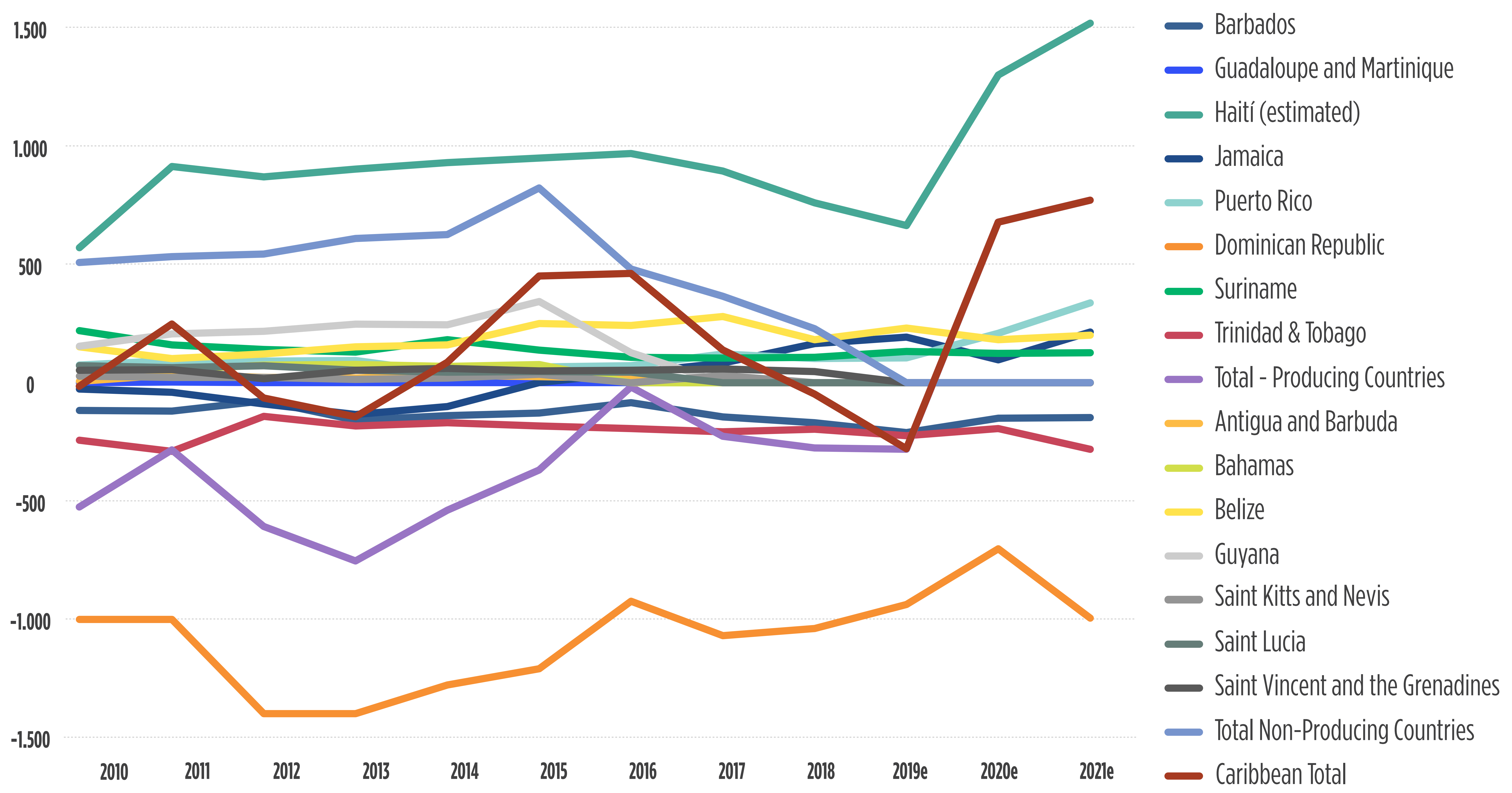
Source: FICEM

2.1.3 Caribbean supply-demand balance and trade

The resulting Caribbean supply-demand balance for cement is shown in Table 2.3 and Figure 2.3 below.

Overall, the Caribbean cement supply and demand were nearly in balance between 2010 and 2015 (the most recent year with data for all countries in the group), flipping from a minor net exporter in 2010 to a net importer of 475,000 tonnes in 2015 (roughly 5% of the regional total demand). The cement producing countries were net exporters throughout the period, averaging near 0.5 mtpa in total net exports, led by the Dominican Republic. Non-producing countries steadily increased their net imports from 0.47 mtpa in 2010 to 0.82 mtpa in 2015.

Figure 2.3: Caribbean cement net imports for select countries



Source: Author based on data from FICEM, UN Comtrade database

Table 2.3: Caribbean cement net imports for select countries (thousand metric tonnes per year)

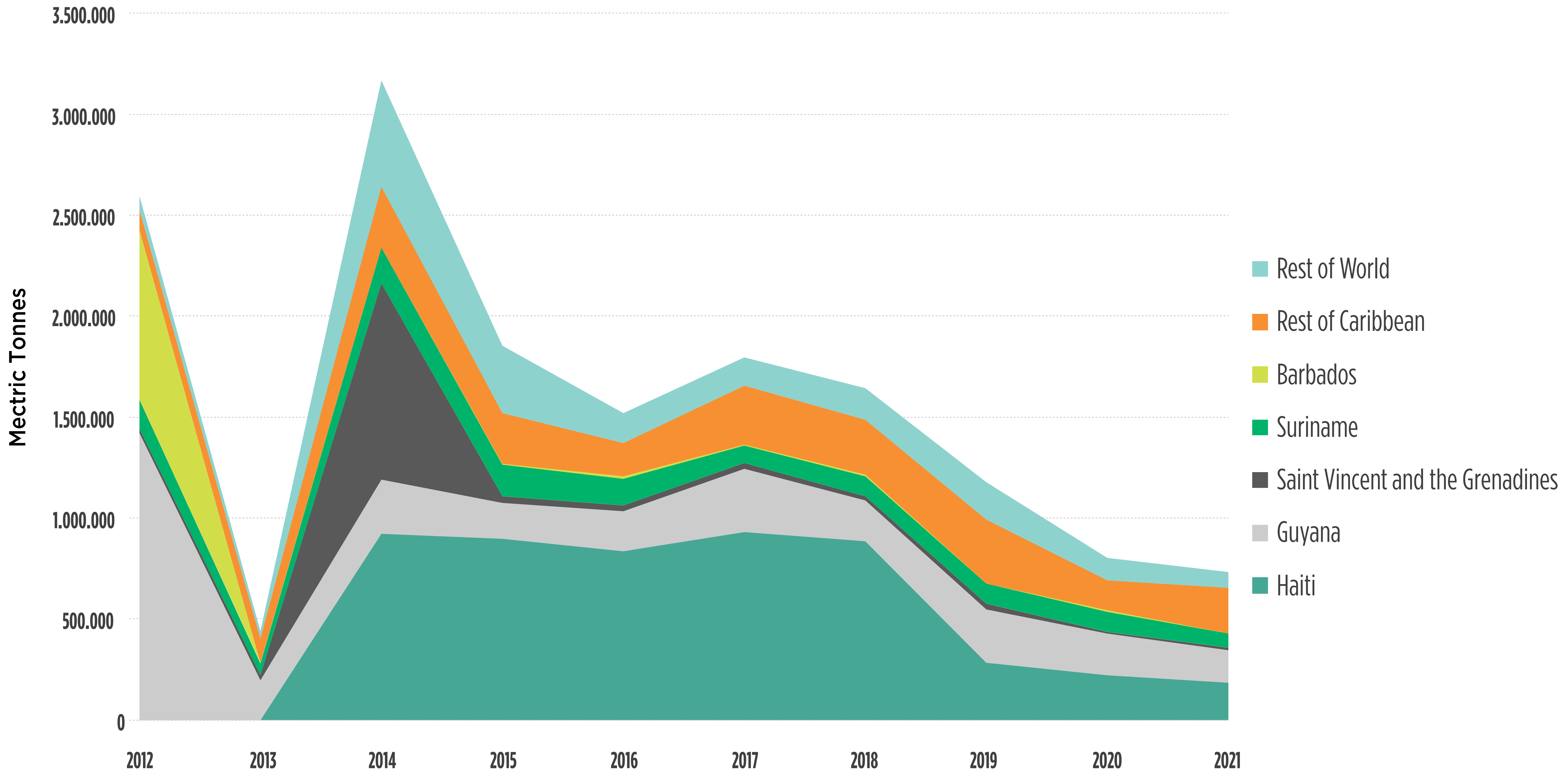
Country	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019e	2020e	2021e
Barbados	-117	-120	-78	-159	-139	-128	-85	-145	-170	-211	-152	-149
Guadaloupe and Martinique	-1	1	0	0	0	0	0	0	0	0	0	0
Haití (estimated)	568	914	870	903	930	948	967	893	758	663	1.300	1.520
Jamaica	-27	-42	-90	-136	-102	0	42	81	165	191	95	213
Puerto Rico	74	94	91	92	40	66	70	120	100	104	209	338
Dominican Republic	-1.000	-1.000	-1.400	-1.400	-1.278	-1.211	-924	-1.071	-1.040	-937	-702	-995
Suriname	220	160	140	130	180	137	106	103	108	132	124	125
Trinidad & Tobago	-243	-292	-142	-184	-171	-184	-195	-209	-199	-224	-196	-282
Total - Producing Countries	**-526**	**-285**	**-609**	**-754**	**-540**	**-372**	**-19**	**-228**	**-278**	**-282**	**678**	**770**
Antigua and Barbuda	5	34	23	19	30	25	20	n/a	n/a	n/a	n/a	n/a
Bahamas	51	54	73	76	69	76	n/a	n/a	n/a	n/a	n/a	n/a
Belize	150	100	120	150	160	250	240	280	181	230	180	200
Guyana	153	204	216	246	243	341	125	n/a	n/a	n/a	n/a	n/a
Saint Kitts and Nevis	27	23	23	13	18	35	n/a	29	n/a	n/a	n/a	n/a
Saint Lucia	70	62	71	52	45	46	44	n/a	n/a	n/a	n/a	n/a
Saint Vincent and the Grenadines	51	55	17	52	59	49	51	57	46	n/a	n/a	n/a
Total Non-Producing Countries	**508**	**533**	**542**	**609**	**624**	**821**	**480**	**366**	**227**	n/a	n/a	n/a
Caribbean Total	**-18**	**248**	**-67**	**-145**	**84**	**450**	**462**	**138**	**-50**	**-282**	**678**	**770**

Source: FICEM

Figure 2.4 shows the destination of cement exports from Caribbean cement producers according to the available UN Comtrade data. The information includes data on total import and export volumes, including the source country for all imports and the destination country for all exports. The trade data was defined by the four-digit HS (harmonized system) commodity code HS 2523. This code includes Portland cement, aluminous cement, slag cement, supersulphate cement and similar hydraulic cements, whether or not colored or in the form of clinkers.

The figure highlights the regional nature of the cement trade as each exporting country tends to send cement primarily to countries that are closest to them: the Dominican Republic's main destination is Haiti, followed by Jamaica; Trinidad & Tobago and Barbados both primarily export to Guyana, Suriname, and Grenada. Few exports leave the Greater Caribbean region.

Figure 2.4: Caribbean Cement Exports by Destination Country



Source: Author based on data from the UN Comtrade Database

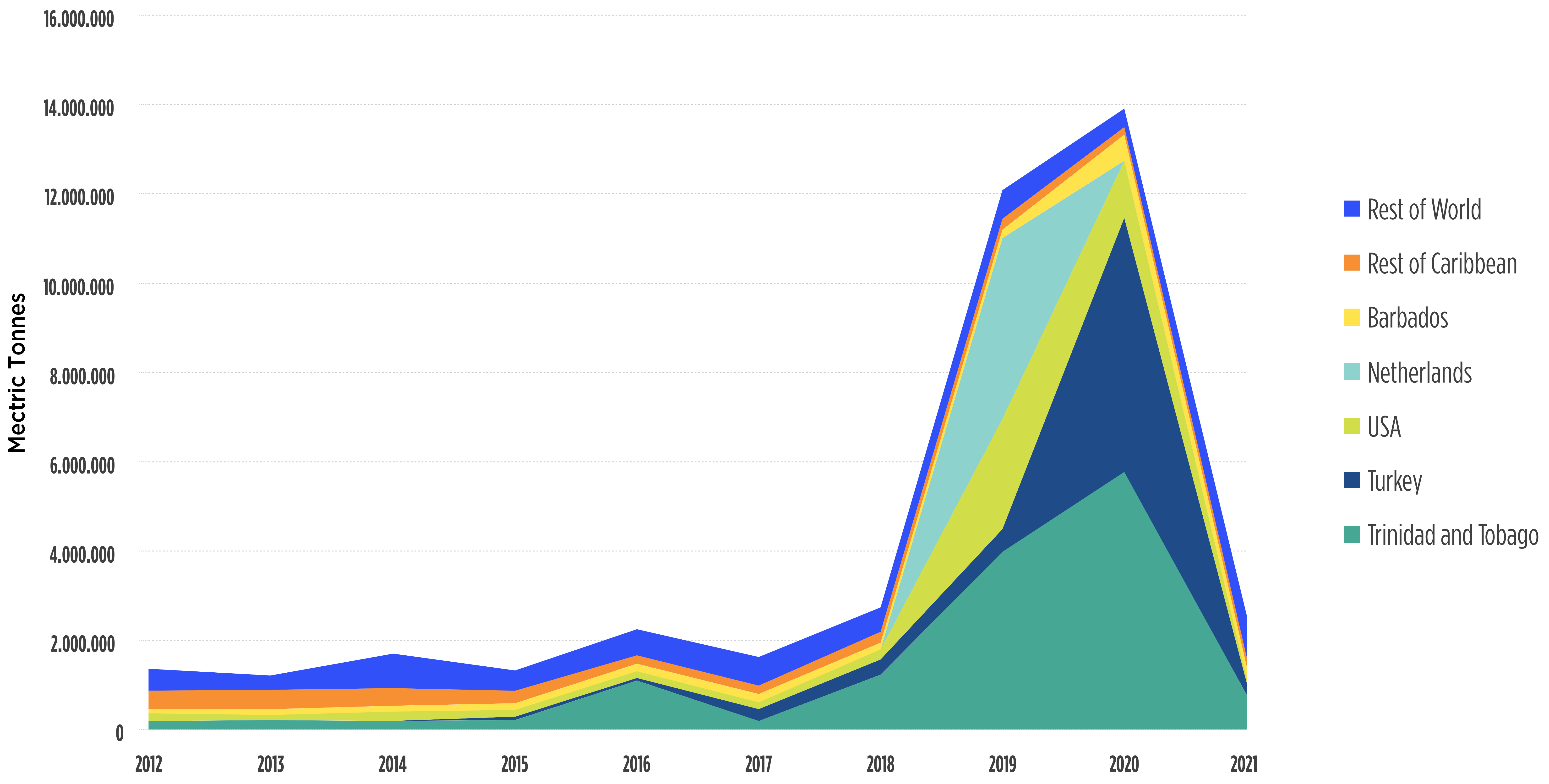
Figure 2.5 shows the other side of the equation by highlighting the source of cement imports for countries in the Caribbean. The data reinforces the trend of regional supply, as the greater Caribbean region (including the USA) is the top source cement for the region through 2018. The most recent data from the UN Comtrade database suggests the region has begun to increase imports from outside the region, particularly from Turkey and the Netherlands. This coincides with a dramatic increase in total cement imports, driven by a surge in cement imports to Guyana and Suriname in 2019 and 2020.

2.2 Steel

Steel is also an important construction material. It is used alone in building components, such as beams and columns, and also as a reinforcement for concrete. This analysis of steel trade within the Caribbean is based on UN Comtrade data for four categories:

- **HS 7213:** Iron or non-alloy steel; bars and rods, hot-rolled, in irregularly wound coils
- **HS 7216:** Angles, shapes and sections of iron or non-alloy steel.
- **HS 7228:** Alloy steel bars, rods, shapes and sections; hollow drill bars and rods, of alloy or non-alloy steel

Figure 2.5: Caribbean Cement Imports by Source Country



Source: Author based on data from the UN Comtrade Database

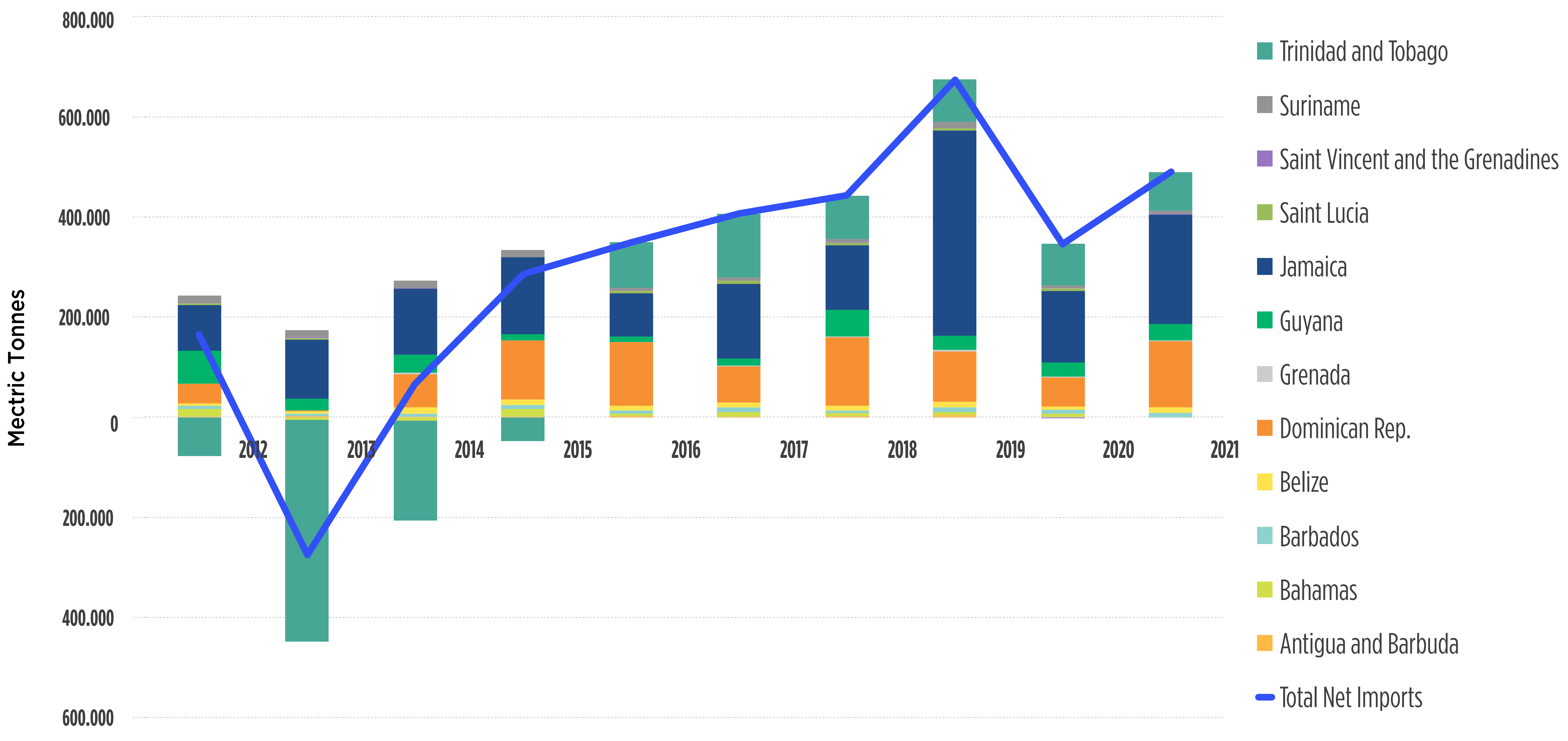
- **HS 7308:** Structures of iron or steel and parts thereof; plates, rods, angles, shapes, sections, tubes and the like, prepared for use in structures

These categories capture the trade of rebar steel, structural beams and elements, and other steel shapes that are commonly used in building construction.

Between 2012 and 2021, the Caribbean region was a net importer of steel in every year except 2013. As shown in Figure 2.6, net steel imports for the twelve Caribbean countries ranged from just below 200,000 metric tonnes to just over 600,000 metric tonnes. Trinidad and Tobago was the only net exporter of steel, and then only until 2015. After 2016, Trinidad and Tobago became a net importer as well.

This overall regional balance is examined in greater detail below, first through the trade data on steel imports and then through the export data.

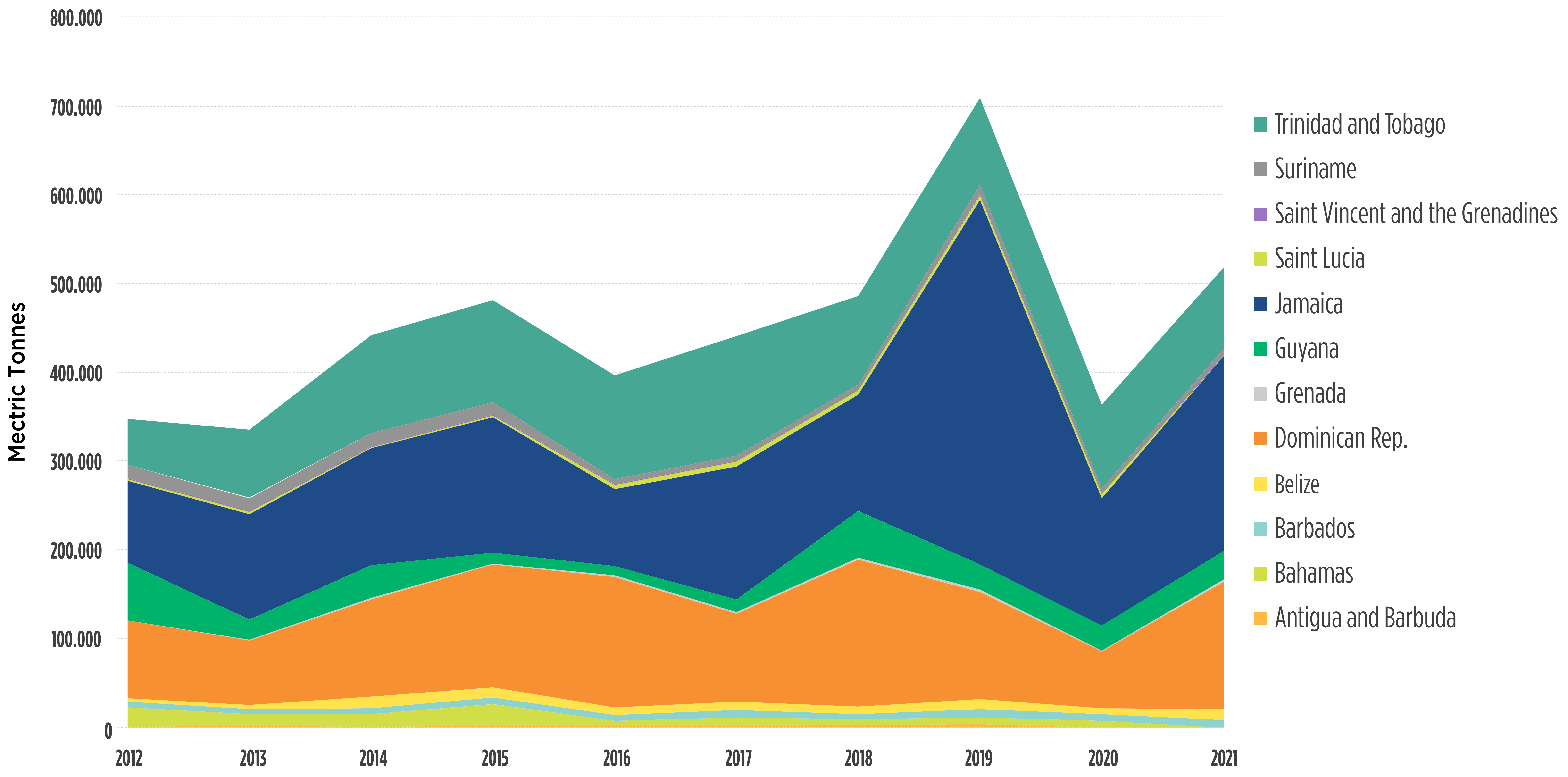
Figure 2.6: Caribbean Net Steel Imports by Importing Country



Source: Author based on data from the UN Comtrade Database

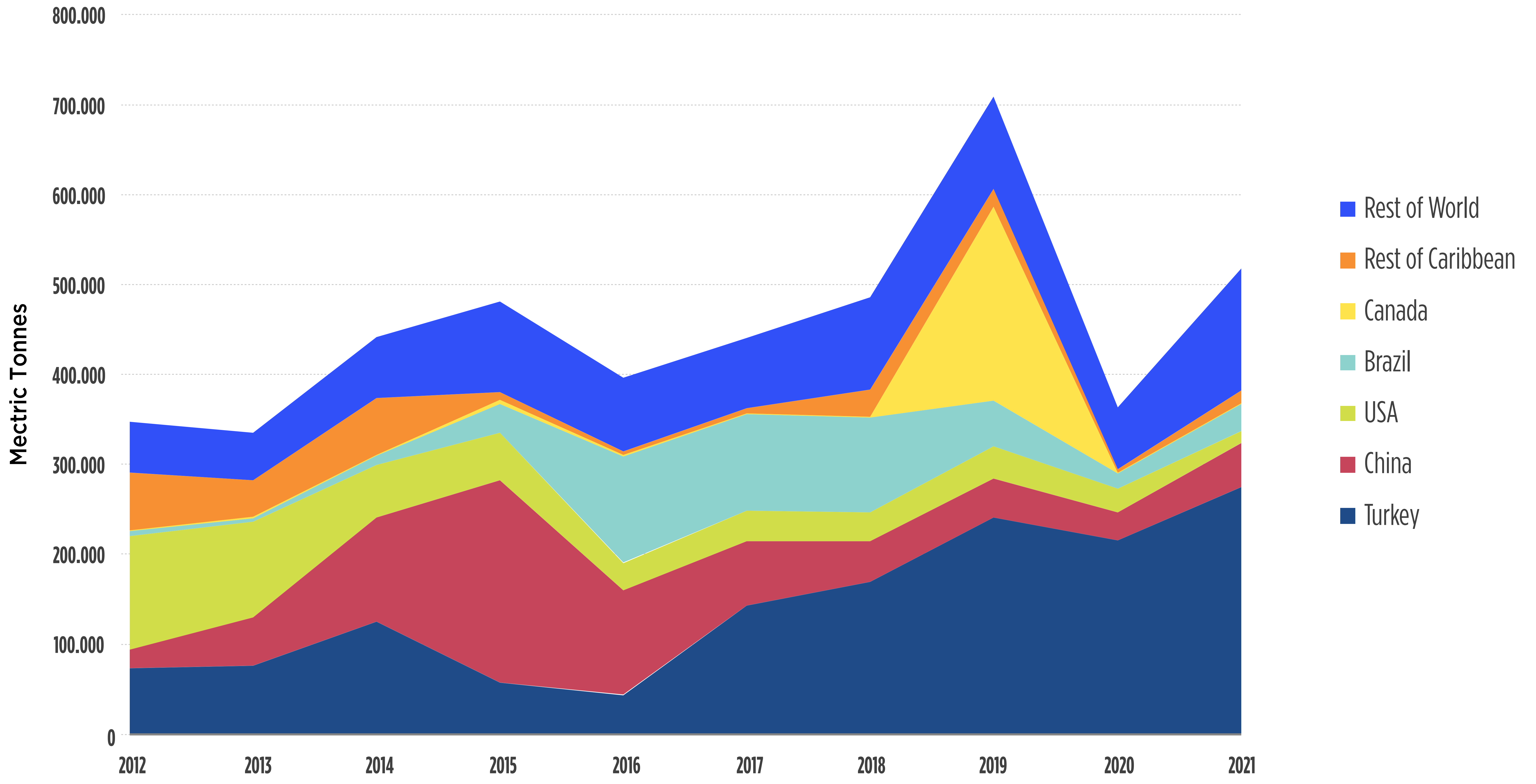
Figure 2.7 below shows the annual volume of construction steel imports for each of the twelve Caribbean countries considered in this analysis. Total imports increased between 2012 and 2019, growing from roughly 350,000 metric tonnes per year to 700,000 metric tonnes, before declining significantly in 2020 and rebounding to 500,000 metric tonnes in 2021. The largest importing countries were the Dominican Republic, Jamaica, and Trinidad and Tobago. Together, these three countries' steel imports accounted for 84 percent of the region on average during the period.

Figure 2.7: Caribbean Steel Imports by Importing Country



Source: Author based on data from the UN Comtrade Database

Figure 2.8: Caribbean Steel Imports by Source Country

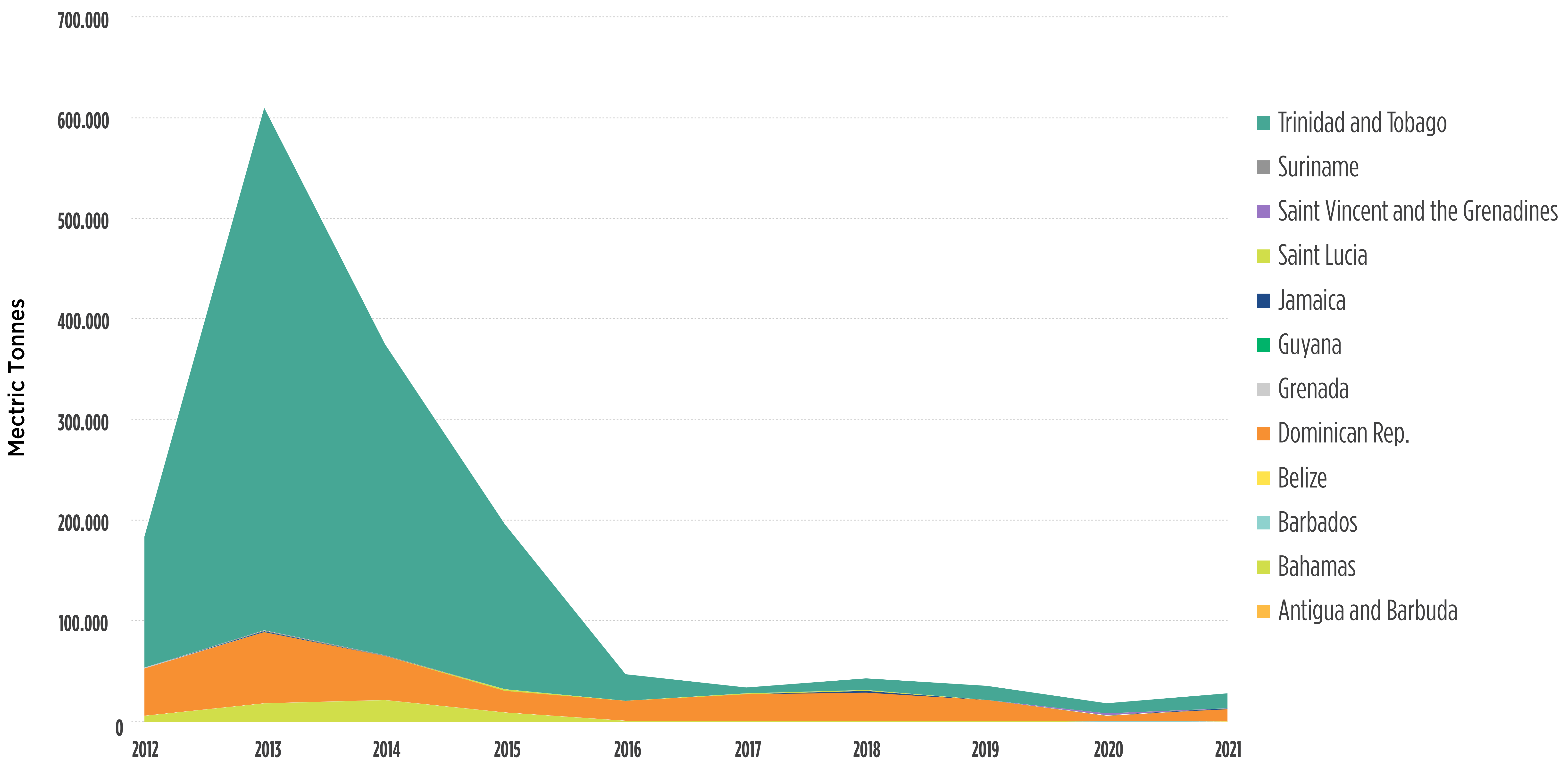


Source: Author based on data from the UN Comtrade Database

Figure 2.8 shows the same steel import volumes in terms of the country of origin, rather than the import destination. The top five sources of steel imports to the Caribbean during the period were Turkey, China, USA, Brazil, and Canada. A small share of the region's steel was imported from Trinidad and Tobago, particularly before 2015. Turkey's share of steel imports to the region has increased significantly in the past five years, growing from 11 % in 2016 to 53% in 2021.

Figure 2.9 below shows the steel exports from each of the twelve Caribbean countries included in this analysis. Trinidad and Tobago is the only country to export significant volumes of steel, and then only before 2015. The Dominican Republic and Jamaica exported very small volumes, including re-exports and exports of steel product manufactured from imported unfinished and raw steel. After 2016, the total volume of reported steel exports was less than 50,000 metric tonnes per year, roughly one tenth the volume of steel imports to the region.

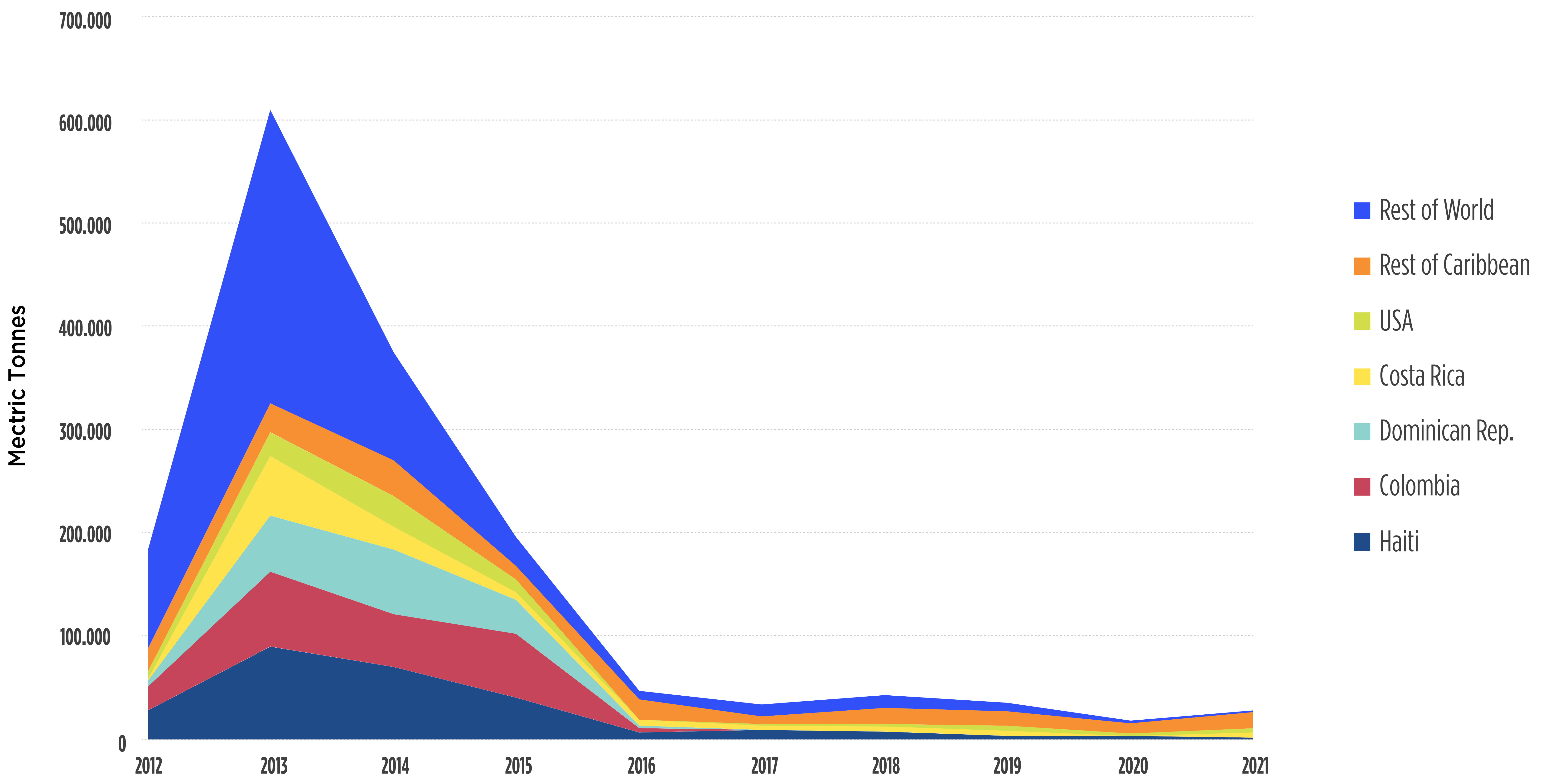
Figure 2.9: Caribbean Steel Exports by Exporting Country



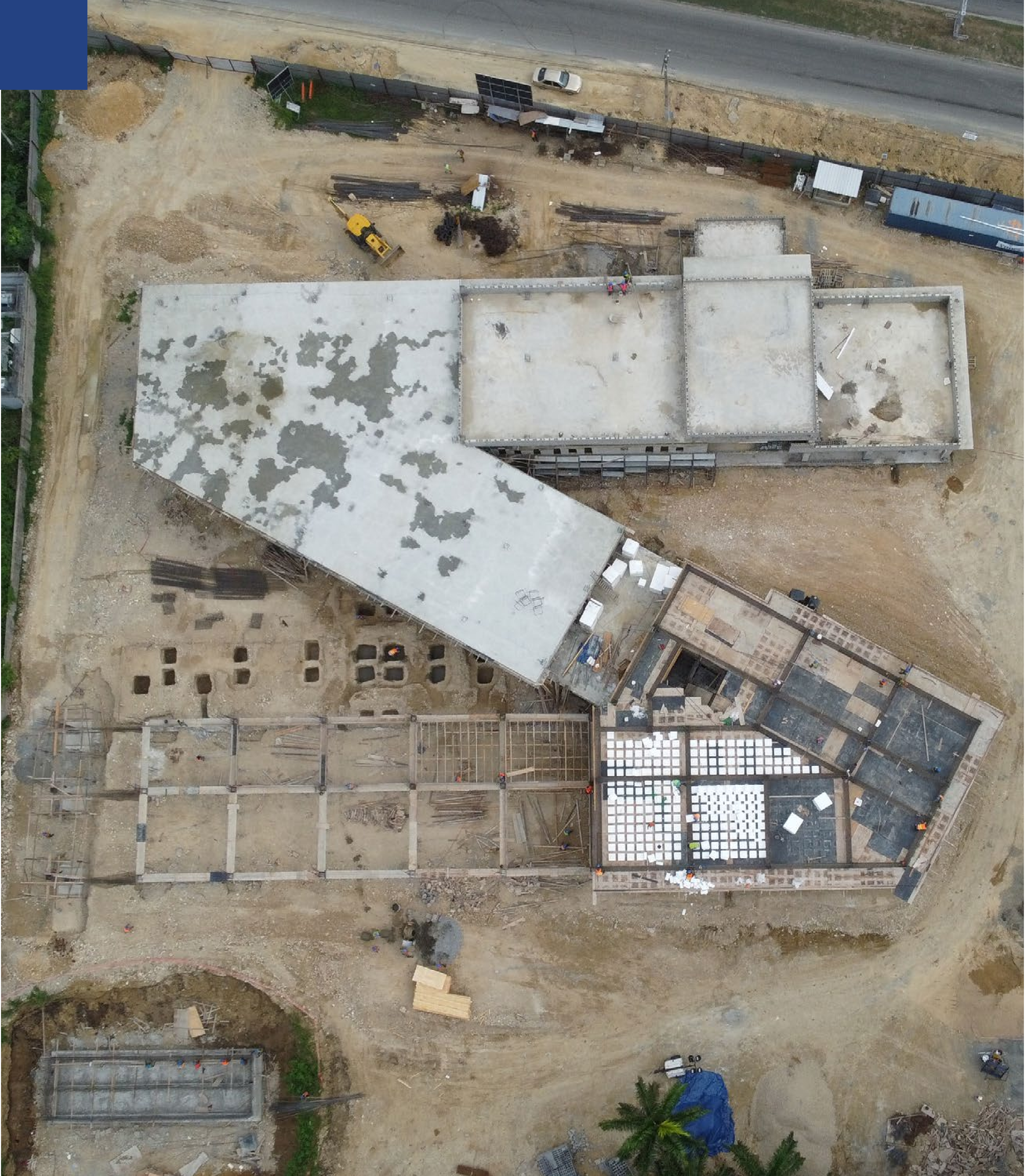
Source: Author based on data from the UN Comtrade Database

Figure 2.10 shows the top destinations for the steel that was exported from the Caribbean. Two of the top five destinations, Haiti and the Dominican Republic, are also within the Caribbean. The other top five destinations, Colombia, Costa Rica, and the USA, are very close markets.

Figure 2.10: Caribbean Steel Exports by Destination Country



Source: Author based on data from the UN Comtrade Database



3. Embodied Carbon in Cement and Steel Used in the Caribbean

This section analyzes the embodied carbon emissions related to the supply of cement and steel to the Caribbean. The analysis considers the carbon emissions that are embodied in the production of the material as well as the carbon emissions resulting from the material's transportation from the country of origin to the Caribbean region.

UN trade data shows that the Caribbean imported cement and steel from a wide range of countries over the past ten years: 74 countries for cement and 130 countries for steel. Many of these countries, however, supplied very small volumes, or supplied materials in only one or two reported years. In order to simplify the analysis, only the largest exporting countries were included.

For each material, this list of large suppliers to the Caribbean region was derived by calculating the cumulative total exports to the Caribbean from each country over the past ten years of available trade data (2012-2021). The list of exporting countries was then sorted from largest to smallest, based on the calculated cumulative total. Those countries representing 90% of the cumulative imports for each material over the past ten years were then selected to be included in the analysis. For cement, eight countries were the source for 90% of the cumulative imports over the period, while ten countries were the source of 90% of the region's cumulative steel imports.

Carbon emissions related to the production for each material in each source country were found based on a literature review of reports from industry, academic, and NGO sources. These sources are listed in the Bibliography. Suitable data was found for all steel source countries and for all but two cement source countries (Trinidad and Tobago and Barbados, both already within the Caribbean region).

Carbon emissions from transporting the materials from the source country to the Caribbean region were estimated based on the average distanced (modeled as the nautical distance between the source country and San Juan, Puerto Rico, a centrally located island), an estimated 455 nautical miles per gallon of fuel per metric tonne of cargo for seaborne shipping, and EIA figures for carbon emissions per gallon of bunker fuel consumed. This calculation resulted in an estimated emissions factor of 0.0247 kg of CO2 emitted per nautical mile per metric tonne of cargo shipped. The carbon emissions per nautical mile were then multiplied by the average distance from each source country to estimate the emissions associated with shipping a metric tonne of material to the Caribbean.

Table 3.1 below shows the calculated carbon emissions per tonne of cement from the eight largest sources of cement imports to the Caribbean. These eight countries represent 91% of the cumulative cement imports into the region between 2012 and 2021. The table combines the CO2 emissions associated with shipping the materials to the Caribbean (based on the distance from the source country to Puerto Rico, chosen as a central reference point for the Caribbean) as well as the reported average embodied CO2 content of cement produced within each source country. The resulting total embodied CO2 for cement delivered to the Caribbean is reported in the final column.

The majority of cement imports into the Caribbean are from producing countries within the region (Trinidad and Tobago, Barbados, and the Dominican Republic, representing 43% of the total) or from countries bordering the region (the USA, Mexico, and Colombia, representing a further 20% of the total. Only Turkey and the Netherlands (representing 28% of total imports) are a significant distance from the Caribbean. As a result, the average distance traveled for cement imports is just over 2,000 nautical miles.

Carbon emissions from shipping are also relatively low, ranging between 5 kg per tonne of cement imported to as much as 128 kg per tonne, with a weighted average of 54 kg per tonne. This wide range mirrors the large differences in shipping distances between sources within the region and exporters from Asia and Europe. Even

Table 3.1: Embodied carbon emissions from top sources of cement in the Caribbean (kg CO2 per tonne of cement)

Cement					
Country	Share of Total	Distance to PR (nm)	Shipping CO2 emissions (kg CO2/ tonne)	Embodied CO2 from manufacturing (kg CO2/tonne cement)	Total Embodied CO2 (kg/ tonne)
Trinidad and Tobago	34%	550	14	820	834
Turkey	18%	5.200	128	813	941
USA	12%	1.700	42	810	852
Netherlands	10%	3.900	96	620	716
Barbados	5%	500	12	n/a	12
Mexico	5%	1.800	44	720	764
Dominican Rep.	4%	200	5	609	614
Colombia	3%	750	19	n/a	19
Weighted Average		**2.168**	**54**	**777**	**830**

Source: FICEM

Table 3.2: Embodied carbon emissions from top sources of steel in the Caribbean (kg CO_2 per tonne of steel)

Steel					
Country	Share of Total	Distance to PR (nm)	Shipping CO2 emissions (kg/tonne)	Embodied CO2 from manufacturing (kg CO2/tonne steel)	Total Embodied CO2 (kg/tonne)
Turkey	31%	5.200	128	1.000	1.128
China	17%	10.700	264	1.950	2.214
USA	11%	1.700	42	950	992
Brazil	11%	3.550	88	1.250	1.338
Canada	5%	2.300	57	1.100	1.157
Trinidad and Tobago	5%	550	14	850	864
Belgium	3%	3.900	96	1.250	1.346
Spain	3%	3.500	86	1.250	1.336
Mexico	2%	1.800	44	1.050	1.094
Rep. of Korea	2%	9.600	237	1.600	1.837
Weighted Average		**5.346**	**132**	**1.289**	**1.421**

Source: FICEM

so, the average carbon emissions from shipping are less than 7% of the average total embodied carbon for cement used in the Caribbean. The weighted average for total embodied carbon of cement used in the Caribbean is 830 kg per tonne. The total embodied carbon from individual source countries ranges between 614 kg per tonne (Dominican Republic) to 941 kg per tonne (Turkey). That is, the source with the highest embodied carbon is roughly 50% higher than the country with the lowest embodied carbon content. Data on embodied carbon from cement manufacturing in Barbados and Colombia were not available.

Table 3.2 below shows the calculated carbon emissions per tonne of steel imported to the Caribbean using the same methodology as was used to calculate CO_2 emissions for cement imports. The analysis includes steel imports from ten countries, representing 90% of the cumulative steel imports into the region between 2012 and 2021.

The majority of the countries exporting steel to the Caribbean are located far away from the region. European and Asian producers (Turkey, China, Belgium, Spain, and Korea) represent 56% of the total. Major suppliers from the Americas also includes countries that are distant from the region, such as Canada and Brazil (representing 16% of the total). Trinidad and Tobago is the only country within the Caribbean region that supplied steel in the past 10 years, with the remaining steel imports from countries that are adjacent to the Caribbean (USA and Mexico). As a result, the weighted average shipping distance for steel imports is over 5,300 nautical miles, more than double the weighted average distance for cement.

Nevertheless, carbon emissions from steel shipping are low relative to the total embodied carbon. Shipping emissions range between 14 kg per tonne of steel imported (Trinidad and Tobago) to as much as 237 kg per tonne (Korea), with a weighted average of 132 kg per tonne. This wide range mirrors the large differences in shipping distances between sources within the region and exporters from Asia and Europe. Even so, the average carbon emissions from shipping are roughly 9% of the average total embodied carbon for steel used in the Caribbean. Embodied carbon from the steel production process ranges from 850 kg per tonne in Trinidad and Tobago to 1,950 kg per tonne in China.

The weighted average for total embodied carbon of steel used in the Caribbean is 1,421 kg per tonne. The total embodied carbon from individual source countries ranges between 864 kg per tonne (Trinidad and Tobago) to 2,214 kg per tonne (China). That is, the source with the highest embodied carbon is roughly 2.5 times higher than the country with the lowest embodied carbon content.

4. Options to Reduce the Embodied Carbon of Cement and Steel in the Caribbean

This section explores three options to reduce the amount of embodied carbon in building materials used in the Caribbean. Section 4.1 examines the impact of prioritizing the least carbon intensive sources for the materials that are used (that is, shifting supply chains to source cement and steel from producers with the lowest carbon intensity). Section 4.2 analyzes the impact of substituting traditional cement-based materials with less carbon intensive alternatives. Section 4.3 investigates the impact of reducing the volume of materials that are used per building through alternative design.

4.1 Adjusting supply chains to prioritize sources with the lowest embodied carbon

The analysis of building material supply chains in the Caribbean in Section 3 suggests that there is a wide range in the carbon intensity of cement and steel among the various sources that supply the Caribbean.

Table 4.1 shows the total embodied carbon for cement from each source country relative to the weighted average embodied carbon of all cement supplied to the Caribbean. The country that provides cement with the lowest embodied carbon (the Dominican Republic) has 26% less embodied carbon than the weighted average of all cement imported into the Caribbean. Turkey, which has the highest embodied carbon levels, has 13% higher embodied carbon than the regional average.

Differences in the embodied carbon in cement are primarily from the different fuels used to generate the high temperatures required for cement manufacturing. Countries with lower embodied carbon have a higher percentage of natural gas or other lower-carbon fuels in the mix of fuels used for cement production, while those with higher embodied carbon have a higher percentage of coal and other high-carbon fuels.

Table 4.1: Relative total embodied carbon emissions from top sources of cement in the Caribbean (kg CO2 per tonne of cement)

Cement			
Country	Share of Total	Total Embodied CO2 (kg/tonne)	Total Embodied CO2 as a Percentage of the Weighted Average (%)
Dominican Rep.	4%	614	74%
Netherlands	10%	716	86%
Mexico	5%	764	92%
Weighted Average		**830**	**100%**
Trinidad and Tobago	34%	834	100%
USA	12%	852	103%
Turkey	18%	941	113%

Source: Author calculations

Table 4.1 demonstrates that supplying all of the region's cement from the source with the lowest embodied carbon (Dominican Republic) would reduce the embodied carbon in Caribbean cement by 26%. The table also shows that the country with the highest embodied carbon (Turkey) is an important source of supply (18% of the total) and has significantly more embodied carbon than the second highest source (the United States). Substituting cement imports from Turkey with imports from any other country that currently supplies the Caribbean would help to reduce the average embodied carbon in the region's cement.

A similar analysis can be made for the steel that is imported into the Caribbean. Table 4.2 shows the total embodied carbon for steel from each source country relative to the weighted average embodied carbon of all steel supplied to the Caribbean. The country that provides steel with the lowest embodied carbon (Trinidad and Tobago) has 39% less embodied carbon than the weighted average of all steel imported into the Caribbean. Steel from China, which has the highest embodied carbon levels, has 56% more embodied carbon per kg than the regional average.

Table 4.2: Relative total embodied carbon emissions from top sources of steel in the Caribbean (kg CO2 per tonne of cement)

Steel			
Country	Share of Total	Total Embodied CO2 (kg/tonne)	Total Embodied CO2 as a Percentage of the Weighted Average (%)
Trinidad and Tobago	5%	864	61%
USA	11%	992	70%
Mexico	2%	1.094	77%
Turkey	31%	1.128	79%
Canada	5%	1.157	81%
Spain	3%	1.336	94%
Brazil	11%	1.338	94%
Belgium	3%	1.346	95%
Weighted Average		**1.421**	**100%**
Rep. of Korea	2%	1.837	129%
China	17%	2.214	156%

Source: Author calculations

Table 4.2 demonstrates that supplying all of the region's steel from the source with the lowest embodied carbon (Trinidad and Tobago) would reduce the embodied carbon in Caribbean steel by 39%. The table also shows that the country with the highest embodied carbon (China) is a major source of supply (17% of the total) and also has significantly higher embodied carbon levels than the second highest source (the Republic of Korea. Korean steel also has much higher levels of embodied carbon than steel from the next three sources (Belgium, Brazil, and Spain), although the Caribbean imports relatively little steel from Korea. Substituting steel imports from China with imports from any other country that currently supplies the Caribbean would help to reduce the average embodied carbon in the region's steel.

Changing the source of material supplies could be limited by the source countries' ability to produce sufficient materials to be the sole source (this is particularly true for materials sourced from the Caribbean), or by contractual and trade relationships among suppliers. Countries with higher levels of embodied carbon may also provide cement and steel at lower prices than countries with lower levels of embodied carbon. A price premium for construction materials with less embodied carbon could be difficult for Caribbean countries with high debt burdens and significant infrastructure needs to justify absent any external aid.

4.2 Switch to less carbon-intensive versions of current building materials

Another approach to reducing the carbon intensity of building materials is to use less carbon-intensive versions of standard building materials. While green steel is not yet commercially available, green cement with reduced carbon content in. In addition, alternative materials can be used in concrete to reduce the amount of cement that is required. These options include:

- **Green cement.** These cements include variations that use alternative cementitious materials to reduce the volume of clinker that is required. For example, Caribbean cement manufacturers owned by CEMEX have begun producing the company's Vertua line of low-carbon cements within the region. The most basic level, Vertua Classic, reduces CO2 emissions by 15-25% from standard cement manufacturing methods. Vertua Plus and Vertua Ultra products can reduce CO2 emissions by up to 70%. Argos, another major cement manufacturer in the region, has also introduced low-carbon products at its Caribbean cement manufacturing plants. Pricing for these products is estimated to range from a similar price as standard cement products to as much as a 50% premium.

- **Concrete blends with reduced cement content.** These concrete products reduce the CO2 content by replacing a portion of the cement used in the concrete mix with other materials that are less energy intensive to produce. The EDGE modeling platform includes two such products: concrete with ground granulated blast-furnace slag (GGBS), and concrete with pulverized fuel ash (PFA).
- **Concrete with ground granulated blast-furnace slag (GGBS).** Molten iron slag is a by-product of producing iron and steel in blast furnaces. When it is quenched in water or steam it produces a glassy, granular product that can be ground into a powder. This powder can then replace Portland cement on a one-to-one basis (by weight) in a concrete mix. GGBS can replace up to 85% of the Portland cement, with shares of 40-50% typically used in most applications. The EDGE modeling software notes that using concrete with more than 25% GGBS can reduce the embodied carbon in a typical floor slab by 26%.
- **Concrete with pulverized fuel ash (PFA).** This blend uses ash left over from burning coal in power plants. Using the ash in concrete production reduces the carbon content of the concrete and also removes the ash that would otherwise pose environmental risks to air and water quality. The EDGE modeling software notes that using concrete with more than 30% PFA can reduce the embodied carbon in a typical floor slab by 24%.
- **Concrete with recycled materials.** Concrete can also be made from recycled materials, such as plastic resins, polystyrene, and rubber. These materials partially replace the aggregate or sand used in the concrete mixture. Like PFA and GGBS, using recycled materials helps to reduce the volume of waste products sent to landfills and to reduce the volume of sand and gravel used in concrete production. These specialty concretes can also have enhanced properties, particularly improved thermal insulation, as well as lower costs.

Although both GGBS and PFA concrete have lower carbon content than traditional concrete blends, there are no blast furnaces in the Caribbean. Therefore, implementing GGBS concrete in the region would require importing the slag material. There are, however, coal fired power plants, including large-scale plants in the Dominican Republic and Puerto Rico, which could provide ash waste for PFA concrete.

Using recycled plastics, rubber or other waste materials could also be a viable option for the Caribbean as many Caribbean islands face challenges in managing municipal waste. Recycled materials are not currently used in concrete production in the region. New facilities would be required to separate viable materials from the general waste stream and prepare them for use in concrete.

4.3 Reduce the volume of carbon-intensive materials used in construction

A third option to reduce the embodied carbon in buildings is to reduce the amount of materials used in each building through innovative design. In particular, alternative materials or designs for the floor slab, roofing, outer walls, and inner walls can significantly reduce the amount of concrete and reinforcing steel used per building. Adopting construction methods that improve construction efficiency and minimize waste can also reduce the total volume of construction materials that are required for a building.

Concrete reinforced with steel rebar is commonly used for building foundations, including floor slabs for residential buildings that do not have basements. It can also be used in slab-style roofs. The amount of concrete and steel used in a building's floor and roofing slabs can be reduced by:

- Applying molds and fillers to shape in-situ concrete applications;
- Replacing in-situ concrete with pre-cast building components that are made at a factory then transported and assembled on site.
- Combining pre-fabricated components and in-situ concrete applications to create composite components that blend the strengths of both.

The World Bank's EDGE database and planning software[5] lists alternative designs that can be used to create slab floors and roofs with less concrete and steel rebar than traditional designs. These alternatives include filler slabs, trough slabs, waffle slabs, precast hollowcore slabs, and precast double tee units. Each alternative is described below.

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5 For more information on the EDGE software see https://edgebuildings.com/

Filler slab flooring and roofing. This design uses filler materials such as brick, clay tiles, and cellular concrete blocks in portions of the slab. This reduces the volume of concrete that is required for the slab. Filler slab also require less reinforcing steel owing to the slab's lighter weight.

Trough slab flooring and roofing. This design uses removable void formers to create trough-shaped spaces while pouring an in-situ slab. This reduces the volume of concrete that is required for the slab. The void formers are removed once the slab is completed and cured.

Waffle slab flooring and roofing. This design uses square removable void formers to create spaces while pouring an in-situ slab. This reduces the volume of concrete that is required for the slab. The void formers are removed once the slab is completed and cured.

Precast hollow core slab flooring and roofing. This design uses precast concrete elements made with internal voids that are joined together at the building site. The internal voids reduce the volume of concrete that is required for the building foundation.

Precast concrete double tee flooring and roofing. This design uses precast concrete elements in a double tee formation (two stiffening vertical beams beneath a single horizontal beam). The double tee reduces the number of elements required and the corresponding number of connections between the beams and supporting columns.

Table 4.3 compares the embodied carbon from these five alternatives floor or roof slab designs to a standard in-situ reinforced concrete slab. The embodied carbon content was calculated from data provided in the EDGE database and from the publicly available Inventory of Carbon and Energy (ICE) database[6]. Some designs require more concrete than a similar standard slab, but also need less steel reinforcement, resulting in a lower overall amount of embodied carbon.

All five of the alternative slab designs had lower embodied carbon than the standard reinforced concrete slab. The in-situ filler slab had the least embodied carbon with just 45% of the amount in a similar standard slab. The thicker trough slab, waffle slab and pre-cast double tee unit options all had more embodied energy from concrete than the standard slab, but also required much less steel, and so had lower overall embodied carbon.

A building's inner and outer walls can also contain large amounts of embodied carbon. The World Bank's EDGE software uses solid brick (that is, clay bricks made with 0-25% voids) with external and internal plaster as the default material for inner walls and outer walls for residential buildings. The software assumes a single layer of bricks (0.1 meter width) for inner walls and a double layer of bricks (0.2 meter width) for outer walls.

Clay bricks have a very high amount of embodied carbon owing to the high heat required to manufacture them. Using materials with lower embodied carbon instead of bricks for the outer and inner walls can significantly reduce the embodied carbon in a building. Potential alternative materials include medium weight hollow concrete blocks, autoclaved aerated concrete blocks, cellular light weight concrete blocks, and plasterboard on timber framing. Each of these alternatives is described below.

Table 4.3: Relative embodied carbon from alternative

Building floor and roof slab designs	Component Thickness	Concrete Volume Relative to a Standard Slab	Steel Rebar Required	Concrete Embodied CO2	Steel Rebar Embodied CO2	Total Embodied CO2	Embodied CO2 relative to Standard Slab
	(m)	(%)	(kg/m^2)*	(kg CO2/ m^2)*	(kg CO2/ m^2)*	(kg CO2/ m^2)*	(%)
Standard In-Situ Reinforced Concrete Slab	0,1	100%	35	26,9	69,7	96,6	100%
In-Situ Filler Slab	0,1	79%	11	21,3	21,9	43,2	45%
In-Situ Trough Slab	0,225	111%	12,5	29,8	24,9	54,7	57%
In-Situ Waffle Slab	0,35	183%	13,1	49,3	26,1	75,4	78%
Pre-Cast Hollow Core Slab	0,1	73%	15	24,6	29,9	54,4	56%
Pre-Cast Double Tee Units	0,35	197%	10,8	65,9	21,5	87,3	90%

*Per square meter at reported thickness

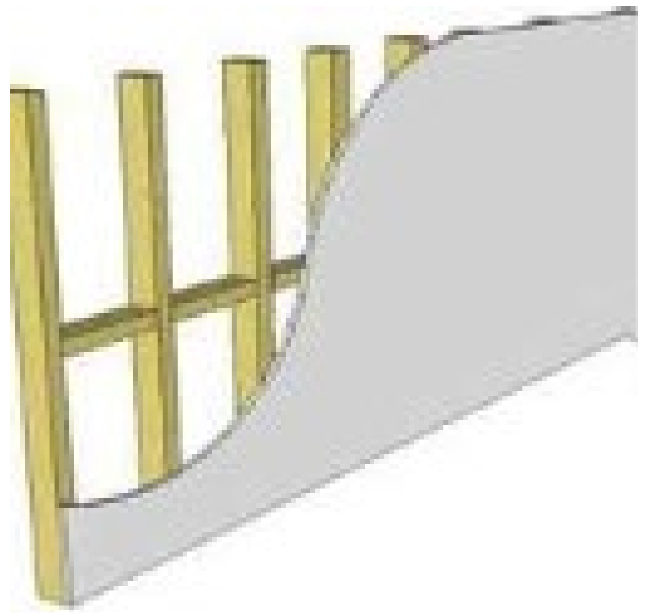
Source: Author based on data from EDGE modeling software and ICE database

6 For more information on the ICE database see https://circularecology.com/embodied-carbon-footprint-database.html

Medium weight hollow concrete block outer and inner walls. This design element uses precast hollow concrete blocks to construct inner or outer walls. They are lighter and have slightly higher thermal insulation than solid concrete blocks. They are larger than traditional bricks, reducing the required number of blocks and amount of cement mortar.

Autoclaved aerated concrete (AAC) block outer and inner walls. This design uses a manufacturing process that increases the volume of air retained within the concrete during manufacturing. This reduces the block's density, and therefore the amount of concrete required for each block.

Cellular concrete block outer and inner walls. This design uses blocks made from a slurry of cement, fly ash, and water to which pre-formed stable foam is added to create small voids within the brick. These voids reduce the block's density, and therefore the amount of concrete required for each block.



Plasterboard on timber studs inner walls. This design uses plasterboard made from gypsum and paper affixed to timber framing for inner walls. It was not considered for outer walls as gypsum is easily damaged by water. Plasterboard requires much less energy to produce than similar brick walls. In addition, the wooden studs can be constructed using sustainably harvested timber, such that they have zero or negative embodied carbon (that is, the wood used in the studs absorbed more carbon during the tree's lifetime than was emitted to manufacture the studs).

Table 4.4: Relative embodied carbon from alternative outer wall materials

Outer Wall	Component Thickness (m)	Embodied CO2 at reported thickness (kg CO2/m^2)	Embodied CO2 relative to Standard Slab (%)
Standard solid brick	0,20	81,9	100%
Hollow concrete block	0,19	26,2	32%
AAC block	0,215	54,7	67%
Cellular concrete block	0,14	23,0	28%

Source: Author based on data from EDGE modeling software and ICE database

Table 4.5: Relative embodied carbon from alternative inner wall materials

Inner Wall	Component Thickness (m)	Embodied CO2 at reported thickness (kg CO2/m^2)	Embodied CO2 relative to Standard Slab (%)
Standard solid brick	0,10	38,0	100%
Hollow concrete block	0,14	21,4	56%
AAC block	0,10	20,0	53%
Cellular concrete block	0,10	16,1	42%
Plasterboard on timber studs	0,125	6,52	17%

Source: Author based on data from EDGE modeling software and ICE database

Table 4.4 compares the embodied carbon of the EDGE software default material (solid brick with plaster) with three alternative outer wall materials. The embodied carbon content was calculated from data provided in the EDGE database and from the publicly available Inventory of Carbon and Energy (ICE) database. For each concrete block option, thicker block designs were used for the outer walls to match the expected width of the default brick wall. All options are assumed to use mortar with a cement-to-sand ratio of 1:4.

All three of the concrete block options had less embodied carbon than the standard brick wall. The cellular concrete block had the least embodied carbon with just 28% of the amount in a similar brick wall. Hollow concrete blocks also had a significant reduction with 32% of the embodied carbon of a similar brick wall.

Table 4.5 compares the embodied carbon of the EDGE software default material (solid brick with plaster) with four alternative inner wall materials. The embodied carbon content was calculated from data provided in the EDGE database and from the publicly available Inventory of Carbon and Energy (ICE) database. For each concrete block option, thinner block designs were used for the inner walls to match the expected width of the default brick wall. The brick and concrete options are assumed to use mortar with a cement-to-sand ratio of 1:4. The timber used in the plasterboard option is assumed to have net zero embodied carbon (this is a conservative assumption as timber can have negative embodied carbon).

All four options had less embodied carbon than the standard brick wall. The plasterboard on timber studs had just 17% of the amount in a similar brick wall. The three concrete block options also had less embodied carbon than the standard brick wall, ranging between 42% (cellular concrete block) to 56% (hollow concrete block).

Table 4.6 below compares the EDGE software default material with the alternative option containing the least embodied energy for each component.

Using the material and design option with the least embodied carbon for each of the four building components results in a 63% reduction in embodied carbon per square meter relative to the EDGE software default materials.

Table 4.6: Reduction in embodied carbon from alternative building materials and designs

Building Component	Default Option	Embodied Carbon	Least Embodied Carbon Option	Embodied Carbon	Reduction in Embodied Carbon	
		(kg CO_2/m^2)		(kg CO_2/m^2)	(kg CO_2/m^2)	(%)
Floor Slab	Standard In-Situ Reinforced Concrete Slab	96,6	In-Situ Filler Slab	43,2	53,3	55%
Roof	Standard In-Situ Reinforced Concrete Slab	96,6	In-Situ Filler Slab	44,2	52,3	54%
Outer Walls	Standard solid brick	81,9	Cellular concrete block	23,0	58,9	72%
Inner Walls	Standard solid brick	38,0	Plasterboard on timber studs	6,5	31,5	83%
Total		**313**		**117**	**196**	**63%**

Source: Author

5. Quantifying Potential Embodied Carbon Reductions in a Residential Building

Section 4 demonstrated that the embodied carbon in resilient buildings in the Caribbean can be reduced through all three methods examined: importing cement and steel from countries whose products have lower-than-average embodied carbon, using low-carbon cement or alternative materials to reduce the carbon content in the resulting concrete, and changing the design and materials of key building components to reduce the volume of concrete and steel that is required.

This section extends the analysis to consider the cumulative benefits from applying multiple methods within a single building. That is, it explores the total potential reduction in embodied carbon from using alternative building component designs built with low-carbon concrete using cement and steel sourced from countries with the lowest average carbon content.

The analysis used the EDGE software to determine the amount of materials required for each of the four building components (floor, roof, outer walls and inner walls). Table

Table 5.1: EDGE parameters for a low-income residential building

EDGE Building Parameters	
Location	**Roseau, Dominica**
Floor Area	60 m^2
# of floors above grade	1
# of floors below grade	0 (Slab Foundation)
Floor-to-Floor Height	3 m

Source: Author based on data from EDGE modeling software

5.1 below shows the basic parameters that the EDGE software assigns to a low-income residential building in the Caribbean.

Table 5.2 below shows the assumptions for each building component.

These parameters were combined with the analysis of the embodied carbon per square meter for each of the EDGE default materials used in the four key building components to calculate the total embodied carbon in the house. Table 5.3 shows the results of this calculation.

Table 5.2: EDGE parameters for key building components

EDGE Building Component Assumptions					
Component	**Ratio of Component Area to Floor Area**	**Total Component Area (m^2)**	**Default Component Thickness (m)**	**Default Component Material Volume (m^3)**	**Default Component Material**
Floor Slab	1,00	60	0,20	12,00	In-Situ Reinforced Conventional Concrete Slab
Roof	1,00	60	0,20	12,00	In-Situ Reinforced Conventional Concrete Slab
Outer Walls	1,27	76,2	0,20	15,24	Solid Brick with External and Internal Plaster
Inner Walls	2,00	120	0,10	12,00	Solid Brick with External and Internal Plaster

Source: Author based on data from EDGE modeling software

Table 5.3: Total embodied carbon in key building components using default EDGE materials (kg CO2)

Material & Design:	Building Component				Total	Share of Total (%)
	Floor Slab	Roof	Outer Walls	Inner Walls		
	In-situ reinforced concrete slab	In-situ reinforced concrete slab	Standard solid brick	Standard solid brick		
Embodied carbon from concrete (kg CO2)	1.614	1.614	0	0	**3.228**	14%
Embodied carbon from steel (kg CO2)	4.179	4.179	0	0	**8.358**	37%
Embodied carbon from other materials (kg CO2)	0	0	6.241	4.560	**10.801**	48%
Total embodied carbon (kg CO2)	**5.793**	**5.793**	**6.241**	**4.560**	**22.387**	**100%**
Share of Total (%)	26%	26%	28%	20%	100%	

Source: Author based on data from EDGE modeling software

Using the default EDGE building materials, the low-income house would have 22.4 metric tons of embodied carbon. The building's embodied carbon is relatively evenly shared across the four main building components. The floor and roof slabs each contribute roughly one-quarter of the total while the outer walls contribute slightly more (28%) and the inner walls contribute one-fifth of the total. This suggests that reducing the embodied carbon in any of the four components would be equally effective.

Of the materials used, the bricks in the inner and outer walls contribute almost half of the total (48%). The reinforcing steel in the floor and roof slabs contribute a further 37% of the total, while the concrete in the two slabs contributes 14%. This suggests that reducing the embodied carbon from the building's bricks and steel would be more effective than reducing the embodied carbon from the concrete.

5.1 Method 1: Adjust materials and designs

The first method to reducing the embodied carbon in the example residential building is to substitute the EDGE software default materials with the materials with the least embodied carbon for each of the four main building components. Table 5.4 below shows the resulting change in the residential building's embodied carbon.

The building using the materials and designs with the least embodied carbon was calculated to have 7.7 metric tons of embodied carbon, a 66% reduction from the default materials. The greatest reduction in embodied carbon came in the outer walls where nearly 5.5 metric tons of embodied carbon was removed (a 72% decrease from the default case). The inner walls had the second highest reduction and the highest in percentage terms: replacing the brick and plaster walls with plasterboard on timber frames cut 3.8 metric tons of embodied carbon or 83%.

The floor and roof slabs each had a greater than 50% reduction in embodied carbon with 3.2 metric tons removed from each. Most of the reduction in embodied carbon in the floor and roof slabs came from reducing the amount of steel rebar that was required. The building's embodied carbon attributed to steel was reduced 69% or by 5.7 metric tons. The embodied carbon from concrete increased by 1 metric ton (34%) as the additional embodied carbon from using cellular concrete blocks for the outer walls more than offset the reduction in concrete used in the floor and roof slabs. The increase in embodied carbon from concrete combined with the significant reductions in embodied carbon from steel and other materials resulted in concrete becoming the greatest source of embodied carbon in the building, accounting for 56% of the total. This is a notable increase from concrete's 14% share of total embodied carbon in the building using default materials, and suggests that further reductions in the total embodied carbon will need to emphasize reducing the embodied carbon from concrete.

Table 5.4: Total embodied carbon in key building components using materials with the least embodied carbon (kg CO2)

Material & Design:	Building Component				Total	Share of Total	Change from Default Case	
	Floor Slab	Roof	Outer Walls	Inner Walls				
	In-Situ Filler Slab	In-Situ Filler Slab	Cellular concrete block	Plasterboard on timber studs		(%)	(kg CO2)	(%)
Embodied carbon from concrete (kg CO2)	1.280	1.280	1.753	0	**4.313**	56%	1.085	34%
Embodied carbon from steel (kg CO2)	1.313	1.313	0	0	**2.627**	34%	-5.731	-69%
Embodied carbon from other materials (kg CO2)	0	0	0	782	**782**	10%	-10.018	-93%
Total embodied carbon (kg CO2)	**2.594**	**2.594**	**1.753**	**782**	**7.722**	**100%**	**-14.664**	**-66%**
Share of Total (%)	34%	34%	23%	10%	100%			
Change from Default Case (kg CO2)	-3.199	-3.199	-4.488	-3.778	-14.664			
Change from Default Case (%)	-55%	-55%	-72%	-83%	-66%			

Source: Author based on data from EDGE modeling software and ICE database

Table 5.5: Total embodied carbon in key building components using cement and steel from sources with the least embodied carbon (kg CO2)

Material & Design:	Building Component				Total	Share of Total	Change from Default Case	
	Floor Slab	Roof	Outer Walls	Inner Walls				
	In-Situ Filler Slab	In-Situ Filler Slab	Cellular concrete block	Plasterboard on timber studs		(%)	(kg CO2)	(%)
Embodied carbon from concrete (kg CO2)	947	947	1.297	0	**3.192**	55%	-36	-1%
Embodied carbon from steel (kg CO2)	919	919	0	0	**1.839**	32%	-6.519	-78%
Embodied carbon from other materials (kg CO2)	0	0	0	782	**782**	13%	-10.018	-93%
Total embodied carbon (kg CO2)	**1.867**	**1.867**	**1.297**	**782**	**5.813**	100%	-16.574	-74%
Share of Total (%)	32%	32%	22%	13%	100%			
Change from Default Case (kg CO2)	-3.926	-3.926	-4.944	-3.778	-16.574			
Change from Default Case (%)	-68%	-68%	-79%	-83%	-74%			

Source: Author based on data from EDGE modeling software and ICE database

5.2 Method 2: Import cement and steel from lowest embodied carbon sources

The next method to reduce the embodied carbon in the example residential building is source the cement and steel used in each component from the country with the lowest average embodied carbon. For cement, this means importing from the Dominican Republic, where the embodied carbon in cement is 26% below the average for all cement imported to the Caribbean. For steel, this means importing from the United States, where the embodied carbon in steel is 30% below the average for all steel imported to the Caribbean.

Table 5.5 shows the resulting change in the residential building's embodied carbon from the reduction in cement and steel embodied carbon.

Changing to the least carbon intensive sources of cement and steel reduced the residential building's total embodied carbon to 5.8 metric tons, a 74% reduction from the amount with the default materials. This total includes 3.2 metric tons of carbon from concrete. This is slightly less than the embodied carbon from concrete in the original example, despite the additional concrete from substituting concrete blocks for the original brick outer walls. The embodied carbon from steel was reduced to 1.8 metric tons, a 78% reduction from the building using default materials.

5.3 Method 3: Use green cement

The final method to reduce the embodied carbon in the example residential building is to use green cement. This analysis used a 20% reduction in carbon content for green cement. This is based on an average of the estimated 15-25% reduction in carbon content that was reported for green cement produced in the Caribbean.

Table 5.6 shows the resulting change in the residential building's embodied carbon from using green cement.

Using green cement in all concrete components reduced the residential building's total embodied carbon to 5.2 metric tons, a 638 kg reduction from using regular cement. Combined, the three methods reduced the residential building's embodied carbon by 77%. The majority of the reduction in embodied carbon came from removing the bricks from the outer and inner walls—both components had an 83% reduction in embodied carbon. The embodied carbon in the floor and roof slabs was reduced 71%. The majority of the reduction came from cutting the embodied carbon associated with steel, primarily from reducing the amount of rebar that was required.

Table 5.6: Total embodied carbon in key building components using green cement (kg CO2)

Material & Design:	Building Component				Total	Share of Total	Change from Default Case	
	Floor Slab	Roof	Outer Walls	Inner Walls				
	In-Situ Filler Slab	In-Situ Filler Slab	Cellular concrete block	Plasterboard on timber studs		(%)	(kg CO2)	(%)
Embodied carbon from concrete (kg CO2)	758	758	1.038	0	**2.553**	49%	-675	-21%
Embodied carbon from steel (kg CO2)	919	919	0	0	**1.839**	36%	-6.519	-78%
Embodied carbon from other materials (kg CO2)	0	0	0	782	**782**	15%	-10.018	-93%
Total embodied carbon (kg CO2)	**1.677**	**1.677**	**1.038**	**782**	**5.175**	100%	-17.212	-77%
Share of Total (%)	32%	32%	20%	15%	100%			
Change from Default Case (kg CO2)	-4.116	-4.116	-5.203	-3.778	-17.212			
Change from Default Case (%)	-71%	-71%	-83%	-83%	-77%			

Source: Author based on data from EDGE modeling software and ICE database

5.4 Comparing the three methods

Table 5.7 below compares the three methods to reduce embodied carbon emissions that are described in this section.

The first method of changing the default case to use designs that require less steel (filler slabs for the floor and roof) or materials with less embodied carbon emissions (timber and plasterboard inner walls and cellular concrete block outer walls) had the greatest impact on reducing embodied carbon emissions. Changing the source of the cement and steel (method 2) or using green concrete (method 3) showed incremental reductions in the embodied carbon emissions, but these improvements were much less than the difference in embodied carbon emissions between the first method and the default case.

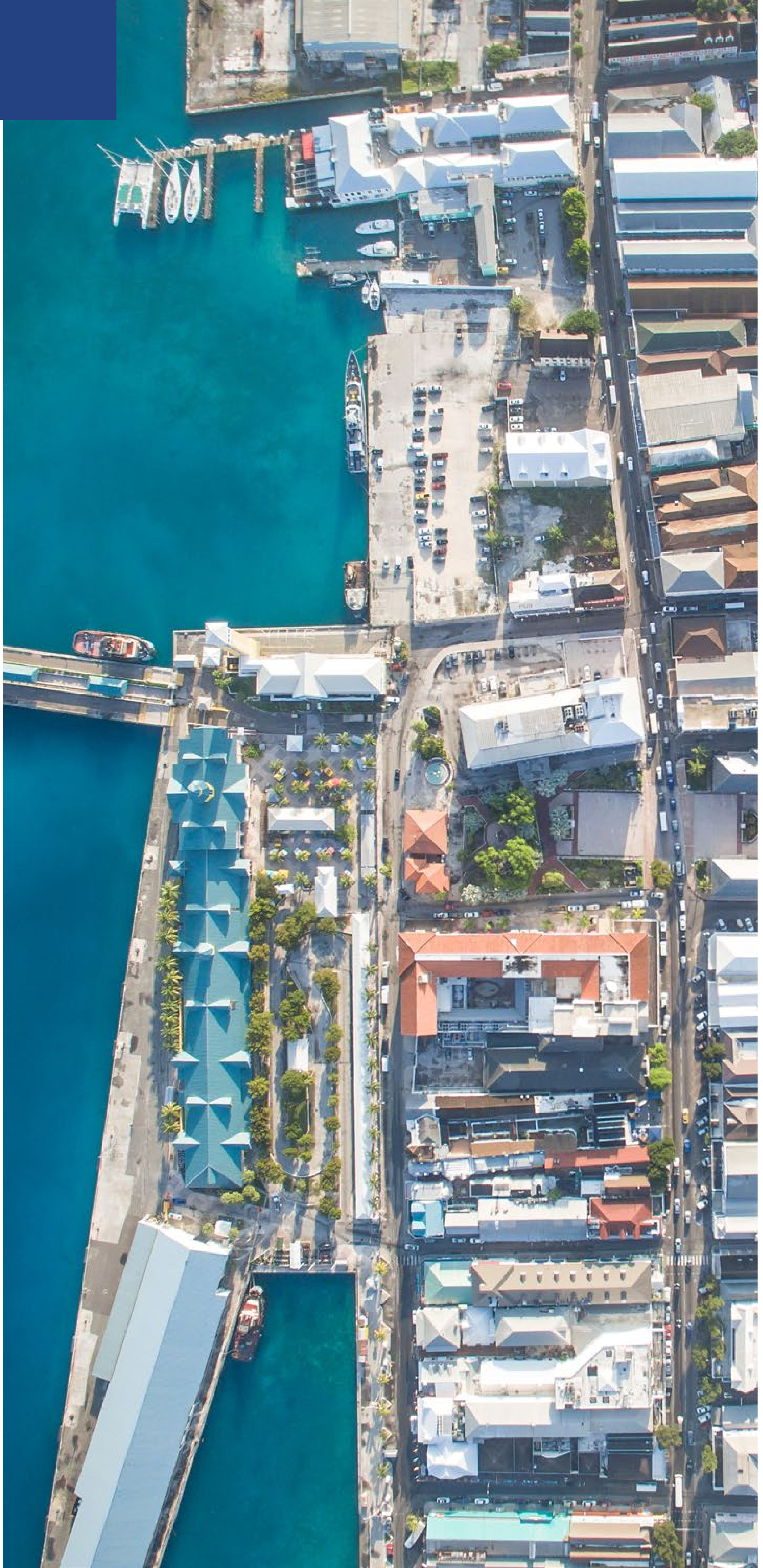
Table 5.7: Comparing three options to reduce total embodied carbon in key building components (kg CO2)

Three options	Building Component				Total	Change from Default Case	
	Floor Slab	Roof	Outer Walls	Inner Walls		(kg CO2)	(%)
	Total embodied carbon (kg CO2)						
Default Case	5.793	5.793	6.241	4.560	**22.387**		
Method 1: Adjust materials and designs	2.594	2.594	1.753	782	**7.722**	-14.664	-66%
Method 2: Import cement and steel from lowest embodied carbon emission sources	1.867	1.867	1.297	782	**5.813**	-16.574	-74%
Method 3: Use green cement	1.677	1.677	1.038	782	**5.175**	-17.212	-77%

Source: Author calculations

This analysis suggests that the embodied carbon in resilient buildings can be significantly reduced through changes in building materials and design. Simply using concrete blocks for the outer walls and plasterboard on timber studs for the inner walls reduced the building's embodied carbon by 37%. Using designs that require less steel rebar also had a significant impact on the building's total embodied carbon.

By contrast, concrete's relatively small contribution to the original building's total embodied carbon limited the impact of reducing the embodied carbon in concrete until after the carbon embodied in the bricks and steel had been abated. For example, using green cement (with 20% less embodied carbon) without any other changes would have reduced the Default Case building's total embodied carbon by just 3%, or 0.6 metric tons.



6. Measures to Incentivize Construction Industry Decarbonization

This section reviews regulatory and financial incentives that can support the implementation of the decarbonization options that were identified and Section 4 and quantified in Section 5. Suggested support includes demand side measures that incentivize the use of lower carbon alternatives and supply side measures that support the production of low-carbon cement and concrete alternatives.

6.1 Demand side measures

These interventions support construction industry decarbonization by incentivizing the use of lower carbon options. Possible measures include:

- **Public procurement.** This approach would leverage government budgets to create a basic level of demand for similar buildings and increases awareness of low-carbon materials and construction methods. For example, RFPs for government building construction could include a maximum allowable amount of embodied carbon per square meter or a minimum reduction in embodied carbon from standard materials and construction practices. Government RFPs could also require the use of specific materials, such as concrete blocks or green cement, if it wishes to support the local production of such materials. This approach has the benefit of requiring relatively little additional funding to cover the incremental cost of lower embodied carbon alternatives, but is limited to only affecting government-sponsored buildings.
- **Government mandates.** This approach would amend building codes and/or town planning guidelines to require all new buildings to be built with materials and designs that have reduced embodied carbon. Similar to the government procurement option described above, these mandates could take the form of a maximum allowable amount of embodied carbon per square meter, a minimum reduction in embodied carbon emissions from standard materials and construction practices, or apply embodied carbon limits to specific materials that are used in construction, such as cement and concrete. This approach has the advantage of expanding the scope of the intervention to include all new buildings, but would require time and, potentially, regulatory changes to implement and enforce the proposed changes.

- **Subsidies.** This approach would budget government funds to subsidize the cost of green cement or other resilient materials with reduced embodied carbon emissions. Subsidies could be set to cover all or a portion of the incremental cost of the reduced carbon emission materials relative to regular building materials, or could be linked to the material's reduction in embodied carbon. That is, materials with a greater reduction would be eligible for a larger subsidy. Green cement costs are estimated to range from a similar price as standard cement products to as much as a 50% premium, such that materials with the highest reduction in embodied carbon emissions also typically have the highest price premium. This approach can reduce any financial barriers to consumer or developer adoption of resilient materials with reduced embodied carbon emissions, but would require ongoing budgetary support from the government.
- **Promoting green cement to increase consumer awareness.** This approach would use advertisements, public service announcements, events, and other promotional methods to increase consumer and developer awareness of the availability and benefits of building with resilient materials with reduced embodied carbon emissions, such as reduced weight and improved thermal insulation from concrete made with plastic resin and other alternative aggregate materials. Such a program can help increase demand for these materials, but has no formal requirement for consumers or developers to adopt their use.

6.2 Supply side measures

These interventions support construction industry decarbonization by incentivizing the production of lower carbon options. Possible measures include:

- **Promoting best practices / cross-industry learning.** This approach would use conferences, events, case studies, and other methods to increase awareness of the availability and benefits of green cement and low-carbon building design across the construction industry in individual Caribbean countries as well as across the region. Such a program can help speed the adoption of best practices and reduce barriers for construction companies to use green materials and design alternatives.
- **Mandating embodied carbon targets for cement and concrete production.** This approach would set the maximum allowable carbon content for cement and concrete produced in a country. The limit could be set to a regional or global average (to encourage companies to adopt available efficiency measures) or set to essentially require all cement to be green cement. This approach would require new regulation and, potentially, legislation, but would be simpler to implement and enforce than similar demand side measures. It may also create stranded assets if it would require companies to discontinue using equipment or invest in new technologies before the existing equipment had reached the end of its economic life.
- **Applying a carbon-based VAT tax to cement, concrete, and steel.** This approach would levy a production tax similar to a VAT that was set according to the level of embodied carbon within the cement, concrete, or steel. That is, materials with higher embodied carbon would be taxed at a higher level than greener alternatives. This would reduce financial barriers to using green cement by removing all or some of the cost difference between green cement and regular cement options. It could also even the playing field between cheaper but higher embodied carbon sources of steel, such as China and Korea, with sources that are more expensive but have less embodied carbon. This approach would function similar to subsidizing materials with less embodied carbon emissions, but would not require government funding to support. It would, however, require new regulation, and, potentially, legislation, to amend the tax code and implement the new taxation.

7. Potential Demonstration Projects

Implementing the decarbonization measures described in Section 6 will require time and government budgetary support, as well as regulatory and, potentially, legislative changes. Pilot projects that are limited in scope can test the assumptions behind the proposed interventions and highlight potential bottlenecks or unforeseen difficulties in implementation before they are applied at scale. This section proposes three demonstration projects that could help governments better understand the potential challenges and benefits from promoting greener resilient housing in the Caribbean. These projects include a demonstration house using the proposed materials and techniques, a test RFP for green resilient government buildings, and a regional conference to share best practices and common challenges to green resilient building in the Caribbean.

7.1 Demonstration house

This project would use each of the design and material options described above to build a resilient home with significantly less embodied carbon. The model home could also incorporate other energy and water efficiency measures to exemplify options that are available to reduce energy and water consumption.

Building the model home would serve to highlight any barriers or unforeseen challenges to implementing the proposed materials and designs in the Caribbean. This could include limited familiarity with the building designs or construction techniques among regional construction firms, limited availability or complex procurement processes for the proposed materials, or significant cost differences in materials or the labor required to build the homes. Demonstrating these challenges can help policy makers focus on specific solutions to alleviate them and facilitate similar construction on a larger scale.

Once completed, the model home can also serve as a public relations and public education tool, by allowing visitors to learn more about how the building was built, the challenge of embodied carbon in buildings, and the benefits from reducing the amount of embodied carbon in resilient buildings.

This demonstration project could be implemented in any Caribbean country. The project specifics can be tailored to the particular needs for each country, such as by adjusting the building design to meet local needs and preferences or by integrating locally available materials into the design.

7.2 Pilot RFP for government building contract

This project would design and implement a pilot RFP process for the construction of a government building or small public housing development using low-embodied carbon designs and materials. The RFP could also require other energy and water efficiency measures to exemplify options that are available to reduce energy and water consumption.

Implementing a pilot RFP would serve to highlight any barriers or unforeseen challenges to requiring government-sponsored buildings to incorporate low embodied carbon designs and materials. These barriers could include limited interest in the RFP from regional construction firms, additional complexities and costs in the RFP development and evaluation processes, or significant cost differences in materials or the labor required for the construction. Demonstrating these challenges can help policy makers focus on specific solutions to alleviate them and facilitate the incorporation of embodied carbon requirements to future RFPs on a larger scale.

Once completed, the pilot RFP can also serve as a model for use in other countries in the region, or for reducing embodied carbon in other government procurement activities.

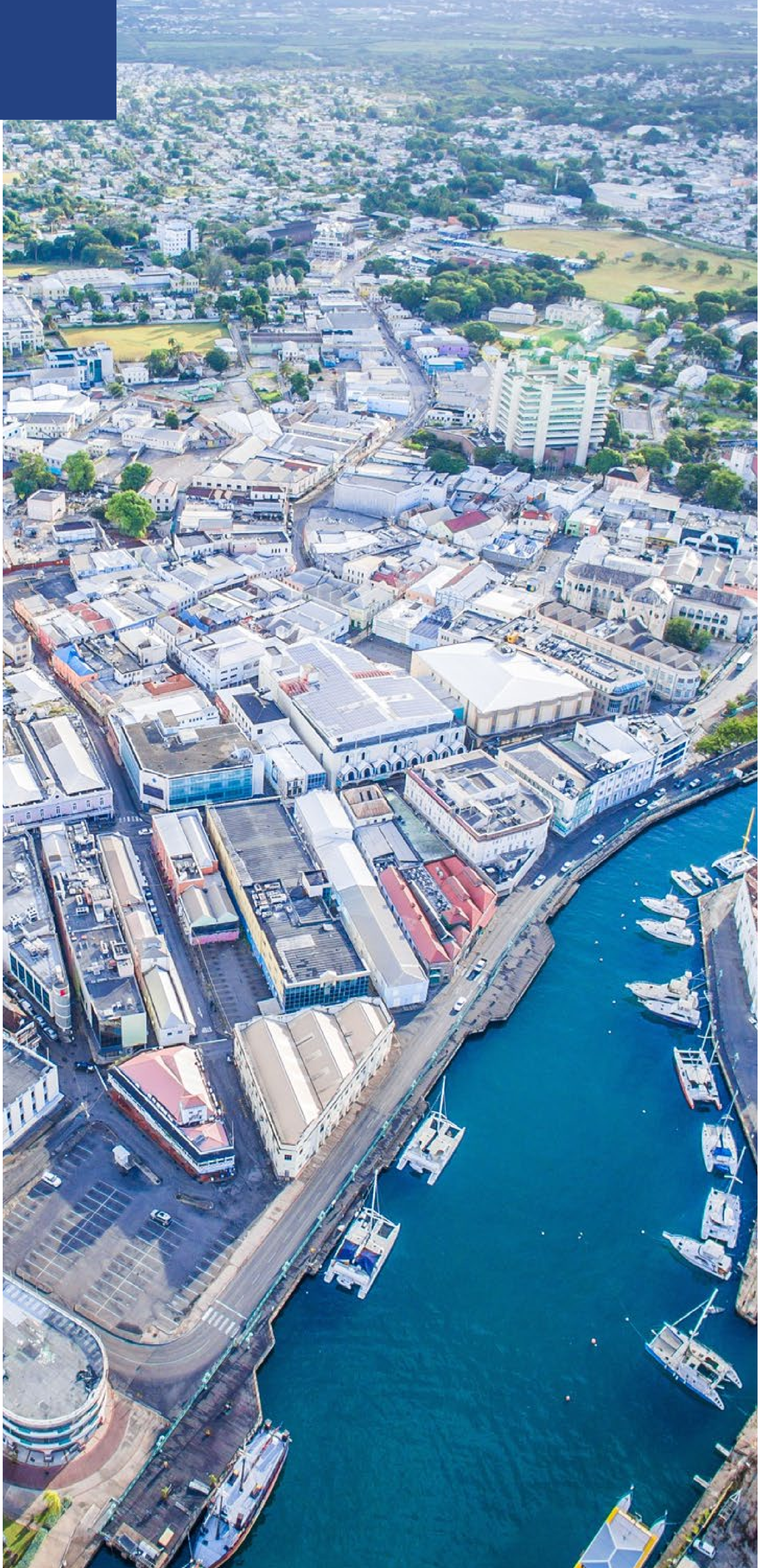
This demonstration project could be implemented in any Caribbean country that is actively building public housing or new government buildings. The project specifics can be tailored to the particular government procurement processes for each country. The implementation can be supported by multi-lateral agencies that provide financing for public housing.

7.3 Regional conference on green resilient building

This project would convene government, industry, and NGO leaders from across the Caribbean and beyond to share their insights on the benefits of reducing the embodied carbon within buildings as well as the challenges to implementing low carbon construction in the region. This event would combine expertise in the regional conditions facing the Caribbean with global expertise in green construction materials and methods to find workable solutions for the region.

Convening an initial conference would highlight lessons learned in green construction in other regions through case studies and presentations by experts and practitioners. An integral part of the conference would be the development of an action plan to support dissemination of any lessons learned about the institutionalization of ongoing dialog to promote continuous sharing of best practices and experiences in green construction.

The initial conference could be implemented in any Caribbean country and could then be repeated annually and held in different countries to ensure the unique barriers and circumstances of each country in the region are represented.



8. Conclusions

This report has examined potential options to reduce the embodied carbon from the use of cement and steel in the Caribbean. The analysis found that nine countries within the Caribbean produce cement, and these countries provide the majority of the cement supplied to Caribbean countries that do not produce cement. The weighted average embodied carbon emissions for cement in the Caribbean was found to be 830 kg of CO2 per tonne.

By contrast, steel used in construction is largely sourced from outside the region, including as far away as China, Turkey, Brazil, and Canada. Trinidad and Tobago is the only country in the region with a history of significant steel exports. The weighted average embodied carbon emissions for steel in the Caribbean was found to be 1,421 kg of CO2 per tonne.

The study explored three broad options to reduce the embodied carbon in cement and steel in the Caribbean: prioritizing the least carbon intensive sources for cement and steel (that is, shifting supply chains to source cement and steel from producers with the lowest carbon intensity), substituting traditional cement and steel with less carbon intensive alternatives, and reducing the volume of cement and steel used per building through alternative designs and elements.

The analysis used the World Bank Excellence in Design for Greater Efficiencies (EDGE) software and database and the Inventory of Carbon and Energy (ICE) database to examine the potential reductions in embodied carbon emissions from applying each of these reduction options in a theoretical construction project.

The EDGE model suggested that the embodied carbon in resilient buildings can be significantly reduced through changes in building materials and design. For example, using cellular concrete blocks instead of bricks for the building outer walls and plasterboard on timber studs instead of bricks for the inner walls reduced the building's embodied carbon by 37%. Applying all three options resulted in a 77% reduction of embodied carbon from the base case.

Implementing the proposed decarbonization measures will require social acceptance by developers, contractors, and building owners. This will take time and government budgetary support, as well as regulatory and, potentially, legislative changes.

Policy interventions to incentivize the implementation of these changes could include demand-side measures such as requiring the use of concrete block outer walls and plasterboard on timber studs inner walls in new residential construction, promoting green cement to increase consumer awareness, or mandating maximum embodied carbon limits per square meter for buildings. Supply-side measures could include promoting best practices and cross-industry learning, mandating embodied carbon targets for cement and concrete production, and applying a carbon-based VAT tax to cement and concrete.

Pilot projects could also be used to test the assumptions behind the proposed interventions before they are applied at scale. This could include building demonstration houses or launching pilot procurement processes for government building contracts using the identified designs and materials The learnings from these pilot projects could then be shared across the region through conferences and publications to help build a shared understanding of the benefits, challenges, and potential solutions to implementing low carbon construction in the Caribbean.

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Social Infrastructure

Building a More Resilient and Low-Carbon Caribbean

REPORT 5

Decarbonization Pathways for the Caribbean Construction Industry

Jed Bailey, Livia Minoja, Alexandra Alvear, Christiaan Gischler

IDB