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Rethinking Caribbean Cities

Adapting to climate change and developing a blue economy

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This report

This study addressed the following key issue: how cities and other centres of population in small developing countries can rebuild and adapt to deliver higher standards of energy, water and resource efficiency. The small island developing nations of the Caribbean were the focus, because these countries represent in microcosm all of the pressures of adapting to increasing pressure on water, energy, land and other resources, sea-level rise, environmental degradation and climate change, and doing so with very limited resources. The specific issues addressed included:

- How cities in the Caribbean can adapt to deliver higher standards of energy, water and resource efficiency.
- How Caribbean islands can increase their energy efficiency, transition to renewables and decarbonize their economies.
- How Caribbean islands can minimize the impact of water shortages, droughts and floods.
- How Caribbean islands can develop the economic role of the blue economy as part of adapting to climate change.

1. Introduction

The period to 2050 will be a time of exceptional turbulence. The world is being rapidly transformed by the scientific advance and technological innovation of the fourth industrial revolution, the transition to a more crowded world with a population that will be significantly older, more urban, and predominantly Asian and African, the shift in the geopolitical balance of power towards Asia, increasing inequalities of wealth, increasing pressure on water, energy, land and natural resources, and the massive disruption of climate change.

The task of navigating such changes, surviving and thriving in a very different world is exceptionally challenging, as the future will be determined by a complex combination of interacting variables; demographic trends, scientific advance and technological innovation, a profoundly serious environmental crisis and increasingly dangerous geopolitical tensions. Success is not guaranteed in navigating such complex challenges and unpredictable outcomes, and plans may be rendered redundant by 'black swan' events, but good governance and proactive planning and preparation will improve the chances of success. As US President Dwight D. Eisenhower said, 'plans are useless, but planning is indispensable'.

The global impact of climate change

All of the trends listed above will involve enormous upheaval, but adapting to climate change will be the greatest challenge. The consequences are already here, the vast fires that caused devastation in Australia, the USA, Canada, the Amazon and Siberia in 2020 are only the beginning; by 2030 more forests and grasslands will have dried out; the fires will be bigger, more frequent, and projected to cause over twice as much damage. Even with the devastating climate events of the last few years, there is relatively little sign that humanity is about to make the radical changes in policies, technologies and lifestyles that would be needed to move the world onto a safer path, and it currently appears unlikely that we will achieve the goal of keeping the average temperature rise to 1.5 degrees. China, which emits more greenhouse gas than all the developed countries of the world combined, has over a thousand coal-burning power stations and plans to build more, with multiple plants under construction at over sixty sites, while India, Indonesia, Japan and Vietnam are also building more coal-burning stations. It would be

necessary to leave almost all the remaining coal and most of the remaining oil in the ground in order to meet the 1.5 degrees target, but the rapid expansion of generating capacity in Asia makes that look unachievable.

On the current trajectory, average global temperatures will rise by 2.7 degrees by 2100, but a further increase in greenhouse gas emissions would mean that the world's average temperature could rise by 4.9 degrees over the same period. This would be completely catastrophic for much of the world. By 2050, sea level rise could inundate nearly 20 percent of Bangladesh; further rises could flood nearly 80 percent of the country. The loss of the Greenland sheet would raise sea levels by 7 metres, drowning the world's coastal cities and reaching far inland. The island nations are highly vulnerable to climate change; the centres of population, hotels, businesses and transport infrastructure are mostly in coastal areas that could eventually be lost, and some low-lying island nations in the Pacific and the Caribbean could disappear.

Rising temperatures could make parts of the Middle East and North Africa uninhabitable within a generation. Accessible fresh water has fallen by two-thirds over the past 40 years; per capita availability of fresh water in the region is now 10 times less than the world average, and is expected to fall a further 50 percent by 2050. The temperature in the areas such as the Persian Gulf region could soon exceed the limit for human survival.

Some 21.5 million people were displaced by climate change-related disasters between 2010 and 2021; the World Bank has estimated that by 2050 there will another 143 million climate migrants. Climate change is not a linear process, and the impacts will escalate dramatically as further thresholds are exceeded. By 2070, about 20 percent of the planet's surface could be uninhabitable, up from just 1 percent today; this would include large parts of South and Central America, Africa, India, Indonesia, South-East Asia and northern Australia. The combination of rising temperatures and sea levels, increasing water scarcity, crop failures and the loss of critical infrastructure in coastal areas will result in migration on a vast scale. Eventually, some tropical and sub-tropical regions would have to be abandoned, and people who have to move into areas that remained habitable, in what could become the largest forced migration in history. It is likely that countries that had been spared the worst effects of rising temperatures would try to close

their borders to the millions being driven out of their own countries, and the risk of war, civil unrest and terrorism would therefore rise sharply.

We are not yet at the point of 'no return'. There is still time to avert the worst of these disasters, but this will require restructuring much of the world economy, with the largest and most extensive set of reforms in history. Over time, this would include rebuilding much of the world's energy infrastructure, automating transport, redesigning cities and investing in new technologies for producing food and managing water.

It is important to note that energy and transport technologies constantly evolve, that patterns of work change as new technologies are introduced and old ones become obsolete, and that cities are always in a process of redevelopment as work and lifestyles adapt. The proposal above, therefore, does not require any revolutionary change; only that governments and planners should find ways to enable progress by encouraging technological development and accelerating dissemination, resolving political gridlocks and institutional inertia, and lowering the barriers to reform. In many instances, this will require focusing on reforms that would not only help to solve the threat of climate change, but would also create new opportunities and thereby support future prosperity.

Differential vulnerabilities to climate change

There are likely to be significant disparities both between and within countries with regard to vulnerability to climate change. For example, tropical and sub-tropical countries are more likely to be affected by water and food shortages and an increased incidence of malaria, dengue and water contamination-related problems, while poor countries lack the means and infrastructure to recover from catastrophic weather disasters. With regard to the domestic distribution of impacts, people with wealth and skills are, in general, better able to move, adapt and protect their interests than poor people. The domestic distribution of impacts will therefore also depend on the distribution of wealth and poverty in society, on levels of education, the availability of good public health services, and on the quality of the housing stock, water, transport and communication infrastructure.

Environmental support systems likely to be sensitive to the impacts of climate change include water resources, land-use patterns (such as agriculture, which will be affected by elevated levels of CO2 in the atmosphere, rising temperatures, changing rainfall patterns, an increased frequency of severe weather events, and changes in the distribution of weeds, pests and pathogens), coastal zones, reefs and fisheries, while the spread of particular disease vectors (such as malaria-bearing mosquitoes) will affect human health. The economic sectors that are likely to be most immediately affected by climate change include agriculture, forestry and fisheries, water services, energy, construction, insurance and tourism. The level of a country's economic development and the structure of its economy are therefore important components of its general ability to adapt to climate change.

These variables overlap, which makes it possible to make generic predictions about the communities that are likely to be most severely affected. For example, the elderly and young children in poor countries, living in coastal communities (e.g. fishing villages) with limited resources, bad schools, basic housing, poor drainage, problems with water contamination, bad roads and limited access to health services, are likely to be among the most vulnerable members of that society.

Developing countries and climate change

The International Monetary Fund (IMF) lists 152 developing countries with a current population of around 6.62 billion people; over 85 percent of world population. Most of them are in Central and South America, Africa, Asia and some in the Caribbean (World Data Info, 2022). Many of these developing countries are particularly vulnerable to floods, droughts, heat waves, and tropical cyclones (Adger W. , 2003).

Climate change and water resources

One of the areas of greatest concern is the potential implications of climate change for water resources. Only 3 percent of the water on the planet is fresh water, with over two-thirds of that frozen in glaciers and polar ice caps (USGS, 2009). Climate change will impact water resources by changing the quantity, variability, timing, form, and intensity of precipitation (EEA, 2020) and increased evaporation rates. Rising air and water temperatures will also have an effect on

water quality by increasing the rates of primary production, organic matter decomposition, and nutrient cycling in lakes and streams, resulting in decreased dissolved oxygen levels (Adams & Peck, 2008).

Agricultural producers and metropolitan regions are particularly vulnerable, as illustrated by recent severe droughts in the western and southern United States, which cost the agricultural and municipal sectors more than US$6 billion. Droughts also exacerbate wildfires, both in terms of control costs and lost timber and other resources.

Countries will gradually adapt to more frequent and severe droughts, which will include redirecting limited water resources to higher-value activities. Such shifts could occur from low-value crops to high-value crops; or from agricultural and industrial to environmental and municipal applications. One of the challenges will be to determine the point at which major investment is required in new systems for managing water; especially as long lead times are involved, and there is an inescapable level of uncertainty regarding the future rate of climate change (Adams & Peck, 2008); over-investing risks an inefficient use of capital, but under-investing (or investing too late) risks catastrophe.

Water security

The 2030 Global Agenda emphasises the strong links between the goals for water (SDG 6) and climate change (SDG 13). Water security is one of the most critical components of any adaptive response to climate change (Babela, Shindea, Sharmab, & Dang, 2020). The possible adverse consequences can be grouped into three categories: too little water (droughts, water shortages), too much water (floods), and excessively polluted water, with extensive implications for all the major water usage sectors such as agriculture, hydropower, fisheries, potable supply, sanitation and industry (Babela, Shindea, Sharmab, & Dang, 2020). Water security therefore has four objectives:

- To safeguard water-related ecosystems
- To achieve political stability and sustainable development
- To ensure that everyone has access to safe water
- To protect against water-related danger (floods, water-borne disease etc.)

For the purpose of this project, we will adopt the definition of water security from UN-Water (2013) as 'capacity that ensures sustainable water use for current and future generations' (Su, Gao, Guan, & Zuo, 2020). Water management is the process of planning, developing, distributing, and managing water resources in order to optimize utilization.

Integrated Water Resources Management

Traditional water management sometimes solved one problem by creating another (e.g. increasing supply to a city at the expense of failing to conserve sources). The Integrated Water Resource Management (IWRM) approach was first developed by the Tennessee Valley Authority (TVA) in 1933 to combine the tasks of navigation, flood management and power generation (Meran & Hirschhausen, 2021).

There are four core components of IWRM; storm-water management, waste-water treatment, water supply maintenance, and water source conservation (APA, 2022). The IWRM approach can also accommodate more complex water problems, which could include, for example, trans-boundary issues between states, competition between agriculture and cities, tensions between traditional/grandfathered water rights and modern demands, unequal competition between commercial and local interests (e.g. for water for tourism versus local people, or water to make soda as opposed to supplying local consumers), pollution of local waterways by large non-local firms, abstraction for human use as opposed to ecosystem maintenance and so on (this reflects the fact that water resources are simultaneously a vital component of the ecosystem, a natural resource, and a social and economic good (UNEP, What is Integrated Water Resources Management?, 2018)).

The IWRM approach has been generally accepted as the way to support efficient, equitable and sustainable development and management of limited water resources and for coping with conflicting demands. The three key policy goals of IWRM are Equity, Ecological Integrity, and Efficiency; the three 'E's:

- Equity: Water is a basic need; everyone has the right to adequate quantities and quality of water.

- Ecological Integrity: Water should be used in a sustainable manner so that future generations will be able to use it in much the same way that we do now.
- Efficiency: Because of its finite and delicate nature, water must be used as efficiently as possible, with appropriate pricing to ensure that waste is discouraged (Meran & Hirschhausen, 2021).

Water quality, water consumption, wastewater disposal and the ecosystem services supplied by aquatic systems are all interconnected, but each of these concerns is still typically treated separately (Bahri, Integrated Urban Water Management, 2012) (Viessman, 1997). The IWRM framework has therefore evolved further to emphasize stakeholder engagement and local community participation in decision-making, and better utilization of specialized knowledge to encourage more innovative solutions, greater co-operation and reduce the risk of conflicts over water resources (Loux & J., 2011).

The Global Water Partnership (GWP) was established to promote IWRM, which aims to ensure the coordinated development and management of water, land, and related resources while ensuring the long-term viability of key environmental systems. GWP as defined IWRM as the process of developing holistic strategies to address the consequences of climate change, urbanization, and other water concerns at the regional and local level, with the ability to scale from buildings to entire catchments (Bahri, Integrated Urban Water Management, 2012).

Urban water issues

The rapid expansion of cities has brought pollution, water shortages, development in areas prone to flooding, subsidence due to excessive ground water abstraction and other hazards. Several new models of urban life have been developed to address these water-related concerns, including the resilient city, eco-cities, and the sponge city. Dijk and Zhang (2019) summarize the three paradigms used in China to deal with urban water issues.

Table 1. Characteristics of different paradigms for urban water management.

Question	Resilient Cities	Eco-Cities	Sponge Cities
What is the definition?	A city able to react to important challenges, like climate change	Eco-cities focus on the social and living environment	A city able to slow, spread, sink, and store water runoff
What are the objectives to be achieved?	Becoming a resilient city and preparing resilience plans	Building an eco-city with water-scaping, as a pleasant place to live	Manage the quantity and quality of water to improve the water environment
What is the role of different stakeholders?	Community involvement is promoted	Role for motivated individuals and project developers	Mainly local government, possibly the private sector
Environmental ambition?	Prepare for environmental hazards	More green, less polluted and an integrated approach	Cleaner water, using natural water treatment processes
Possible solutions?	Adaptation, prepare for challenges	A different type of planning is suggested	Technical options and private participation
A relevant reference	OECD (2018) and Rockefeller Foundation (2014)	Bhatnagar (ed., 2010) and Wong and Yuen (eds, 2011)	Li et al. (2017) and Liang (2018)

There are significant differences between these three paradigms; the resilient and sponge city paradigms have a narrower application, whereas the green, eco-, and sustainable city concepts are extremely broad. The resilient and sponge city paradigms are primarily concerned with the use of government mechanisms, but the eco-cities paradigm emphasises the role of citizens and NGOs in new governance structures.

Urban Water Security

Urban water security has three pillars: water resource security, water environment security, and water disasters security. *Water resource security* is mainly concerned with water shortages, where water supply has become more difficult as a result of climate change and human activities, so people are increasingly relying on non-traditional water sources, such as desalination, rain, and reclaimed water. *Water environment security* is mainly concerned with water pollution, and the degradation of wetland ecosystems, eutrophication of water bodies, and bloom outbreaks. *Water disaster security* focuses on water-related destruction, such as floods. The purpose of investing in urban water security is to support the economy and society that depends on stable supplies and protection from harm.

Cities with Integrated Water Resources Management

Some cities have started to use the IWRM model to manage water, with various different approaches.

Sponge City

A 'Sponge City' is one that has the necessary planning, legal frameworks, and instruments to construct, maintain, and adjust infrastructure systems for collecting, storing, and treating storm water and rainfall. A sponge city has the capacity to absorb and store heavy rain and surges of storm water and to use this water to address the problems of insufficient regular water supply or excessively polluted water (Zevenbergen, Fu, & Pathirana, 2018).

Figure 1: Sponge Cities – China's Weapons Against Floods

China

Since 1980 China's metropolitan population has expanded six-fold, to around 750 million people. China's urban population is now over 54 percent of their total population (Zevenbergen, Fu, & Pathirana, 2018).

China has serious water challenges, including scarcity, flooding and water pollution. Urban water problems have become pressing as a result of the rapid expansion of industry, increasing urbanization and the rising frequency of extreme weather occurrences (Zevenbergen, Fu, & Pathirana, 2018). As a result, the Sponge City concept is gaining traction. China's State Council has set ambitious national targets for the uptake and implementation of the Sponge City concept (Zevenbergen, Fu, & Pathirana, 2018).

Urban Water Management

Urban water includes natural surface water, groundwater, potable water, sewage and other 'waste' waters, rain and storm-water. The goal of the Urban Water Management concept is to improve the management of all forms and flows of water, including water use efficiency, better water services and recycling (using 'third pipe', storm-water harvesting, sewer mining, managed aquifer recharge and other techniques).

To achieve the goals of urban water management, cities must manage their urban hydrological cycle. This includes:

- Developing water security through making optimum use of the various available water sources
- Safeguarding and restoring the health of waterways and wetlands
- Reducing the risk of flood and damage
- Creating public and private spaces that can buffer, purify and recycle waste/flood water.
- Ensuring a sustainable and resilient supply of water for urban communities (The Department of Water and Environmental Regulation, 2017).

Sustainable Urban Water Management

Under this model, the goal is not just to make water resources available, but to ensure efficient utilization (Zafirakou, 2017). Sustainable management of urban water systems therefore requires elements of physical, financial and behavioural engineering (Sodiq, et al., 2019).

Issues with Integrated Water Resource Management

The challenge for the IWRM model is the increasing difficulty in reconciling a number of potentially incompatible goals, such as meeting the increased demand for water as urban

populations grow while still protecting and conserving water resources, and simultaneously meeting a range of other targets, including:

- Securing adequate clean water for people
- Providing water for food production
- Providing water for industry
- Protecting vital ecosystems
- Managing the variability of water in time and space
- Managing risks
- Increasing public awareness and understanding of the challenges.
- Complying with regulations.
- Ensuring collaboration across sectors and boundaries

As populations grow and living standards rise, so will the demand for high-quality urban and industrial water, as well as the output of sewage. Simultaneously, more irrigation water will be required to meet rising food demand for growing populations, and demand will rise for environmental considerations such as aquatic life, wildlife refuges, recreation, aesthetic qualities, and riparian ecosystems, all of which implies that more water will be necessary (Bouwer, 2000). This makes it increasingly important that water prices and allocations should reflect the true costs of developing and delivering water supplies and maintaining the system.

Water issues in the Caribbean

The Caribbean has some of the most water-scarce nations on the planet, including Barbados and the Bahamas, as well as countries with abundant freshwater resources, such as Guyana and Belize (Cashman A. , Why isn't IWRM working in the Caribbean?, 2017). The small islands are most vulnerable to rising demands on their water resources (Cashman et al., 2010; Falkland, 1999; Payet and Agricole, 2006), as they have to balance land, population, and water resource constraints, meet the demand for economic development and social well-being, and control over-fishing, groundwater and marine pollution (GWP, 2014). The relative importance of surface and underground water varies from island to island. Groundwater, for example, is the principal source of water for Barbados (Farrell, Nurse, & Moseley, 2007).

Changes in rainfall patterns will impact the rate at which aquifers replenish, and sea level rise will result in saline intrusion into groundwater in some areas, both of which will reduce freshwater availability. At the same time, climate change will increase the rate of beach and coastal erosion and the impact of tropical storms, which will jeopardize the vital tourism industry (Deeb, 2002); one of the main sources of revenue and employment. Water resource management on Caribbean islands will therefore become increasingly important but also increasingly difficult at the same time (Farrell, Nurse, & Moseley, 2007).

Impact of climate change on Caribbean agriculture

Climate change is likely to have multiple impacts on agriculture in the Caribbean, including:

- Scarcity of water for irrigation; drought reduces the soil's environmental carrying capacity and productivity, and sea level rise can induce aquifer salinization and the loss of coastal agricultural fields.
- Temperature and humidity changes can extend the range of pests and imported species.
- Changes in rainfall patterns and temperatures impact crop yields, influencing food prices and availability.
- Drought, heat stress, and dry pastures diminish feed availability, increasing animal mortality and increasing production costs through higher use of concentrate feed.

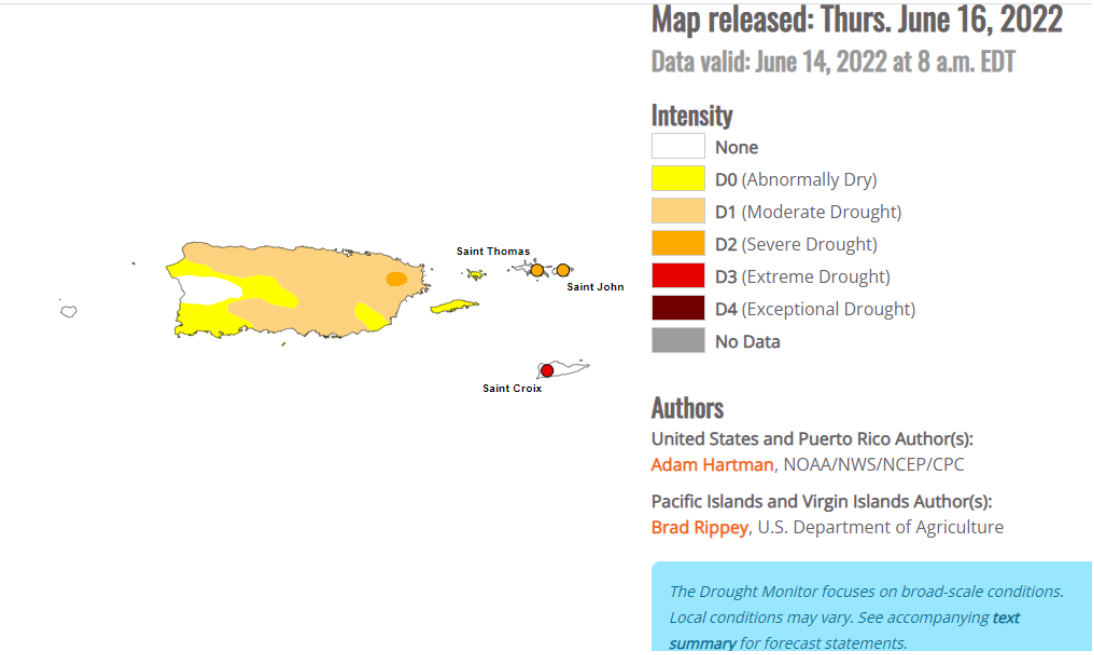
Many of the Caribbean islands import most of their food, in some cases over 90 percent. Agriculture is only a small fraction of the formal economy of most of the Caribbean nations, but it still plays a disproportionately large social role, as it provides food security and livelihoods for many in rural communities who would otherwise be destitute. A drop in agricultural productivity will primarily affect these lower-income populations, sharply increasing the worst effects of poverty (Bierly, 2019).

"*Agriculture should be part of the solution and we must support the countries of the Caribbean in generating the conditions that will allow them to be more resilient to climate change, while ensuring an*

Figure 2: Project beneficiaries will be farmers, non-governmental organizations, governments, entrepreneurs, and youth, among others (IICA, 2021).

adequate and quality food supply for their people". - Manuel Otero, Director General of IICA, (IICA, 2021)

Almost all Caribbean countries have been experiencing extended periods of drought, and temperatures and seasonal rainfall patterns are projected to become more erratic in the future (Centers, 2020). In Puerto Rico, for example, a severe drought between 2014 and 2016 resulted in water rationing and agricultural losses totalling more than $14 million. The impact can be seen in the figure below:



> *"There are drought and water shortages and that affects crop production and animal production. This year we had many of our animals dying because they didn't have water and they didn't have water for the foragers,"*
> - Ena Harvey, the Barbados representative for the Inter-American Institute for Cooperation on Agriculture (IICA) (Brown, 2015).

Local communities in Jamaica already have some indigenous and traditional coping strategies (recorded in Jamaica by Gamble et al. (2010), including mulching for soil moisture retention, crop diversification, and adjustments in crop season and water storage (ODPEM, 2010). The importance of these local initiatives has been recognized in the National Hazard Mitigation

Policy (National Hazard Mitigation Policy Development Committee, 2005) which focuses on ways to reduce vulnerability. The National Hazard Mitigation Policy lists a wide array of sources of hazard vulnerability in Jamaica, including inappropriate land use, environmental damage, high levels of poverty, inequity and exclusion, a lack of effective government action and low levels of institutional/organizational collaboration (Selvaraju, Trapido, Santos, & Mar Polo Lacasa, 2013).

Climate change, water and healthcare in the Caribbean

About 65 percent of Latin America and the Caribbean's population of over 650 million still lack adequate access to safe drinking water (PAHO, 2020). Water-related infections and microbial events, such as cyanobacteria algae blooms, have affected a number of areas in Latin America and the Caribbean, highlighting the need to integrate solutions for water contamination between urban and rural areas, and between water, agriculture, and health sectors. Higher temperatures will increase the risk of water and mosquito-borne diseases, such as dengue (Hallegatte et al., 2016, Watts et al., 2015); (Cárdenas, Bonilla, & Brusa, 2021).

The US Global Change Research Program (USGCRP, 2016) lists the following likely health impacts of climate change:

- Increased morbidity rates as a result of extreme weather events such as floods and heat waves
- Increases in vector-borne diseases as a result of rising temperature and disruption of weather patterns
- Increased risk of water-related infections.

The interaction between climate change, health and disease transmission, and related variables such as land-use change and migration is particularly complex, which complicates the task of developing a policy response (Cárdenas, Bonilla, & Brusa, 2021) as a number of government ministries would have to coordinate their interventions.

2. Urban redevelopment as a climate change adaptation strategy

Many coastal cities will be at increasing risk of extreme weather events, with high winds and storm surges that exceed the capacity of most current drainage systems, which were designed for far smaller volumes of water. By 2050, nearly 70 percent of the world's population will reside in cities, and about 90 percent of those cities will be in coastal areas, which means that nearly 1 billion people will live in areas that may then flood regularly. Major storms are also becoming more frequent, reducing the time to rebuild and recover in between. As a result, most existing disaster preparation plans are rapidly becoming obsolete (Piore, 2022).

However, cities are also a vital part of the solution. One of the most important ways that a country can drive the restructuring of its economy to operate on a far more sustainable basis is to redevelop its cities. Cities can support smart systems for housing, transport, food, water, waste, sanitation, work and living, they can be redesigned to give greater resilience to pandemics and environmental disasters, and they have the population density needed to make services more efficient and the market size needed to support innovative solutions. Cities have served as engines of development for centuries, but their increasingly complex multi-functional role is now crucial to achieving the Sustainable Development Goals.

A number of cities around the world are now experimenting with telecommuting, low-carbon mobility options, permeable spaces to reduce social tensions, the integration of water and storm-water management, the use of wetlands and parks to improve air quality, the development of urban agriculture to utilize grey water and harvested rainwater, the mitigation of natural hazard risks with appropriate zoning and building codes, and the remodeling of homes, offices and public spaces to allow distributed working and social distancing. Many of these ideas are captured in the concept of urban resilience, where resilience is defined as the ability to maintain essential services and functions throughout major perturbation (Clayton, 2013).

The concept of urban resilience does not stop at the city limits. It has to extend outwards into the wide network of supply chains, energy and water sources, services, trade and travel patterns that sustain cities and link them into the rest of the world. As the social, economic and environmental ‘footprints’ of cities extend far beyond their borders, so the social and ecological repercussions

of decisions made in metropolitan areas also extend far beyond the city limits (Dodman, Diep, & Colenbrander, 2017).

Urban resilience

There are significant challenges, however, in translating the idea of urban resilience into actual, viable policies. The challenges start with the fact that resilience itself is a complex concept. In ecology, it refers to the capacity of the system to resist damage and recover quickly. All systems have some ability to resist perturbation, or they rapidly cease to exist as systems. However, resilience does not imply the absence of change, as external conditions will themselves vary, but rather the ability to stay abreast of external changes and adapt to new circumstances.

This is not always possible, of course, as a very large or abrupt change may alter the situation to an extent or in such a short time that the system cannot adjust, but dies out instead. The cause of extinction might be a rapid or extreme event (such as a large asteroid strike), where the impacts are concentrated into a brief period, or a slow onset event (such as climate change) where the impacts may increment over years but eventually go past the point at which further adaptation is impossible.

Systems stressed beyond their capacity to recover may undergo an irreversible transition to a different state. Once a 'keystone' species has become extinct, for example, the habitat is irrevocably changed; many other species are affected, and some may disappear from that ecosystem or become extinct as a result.

With regard to socio-economic systems, resilience refers to the ability of an economy to continue to generate wealth and employment throughout technological discontinuities, economic restructuring, the loss of uncompetitive businesses and shocks such as a spike in energy prices. As this suggests, resilience does not mean resisting change, it means maintaining system integrity and output while continuously adjusting to changing circumstances. This flexibility is a common attribute of competitive market economies, largely because the process of creative destruction encourages innovation and destroys obsolete methods, but it is less often seen in economies dominated by *rentier* capitalism, state monopolies, corrupt parastatals or authoritarian centrally-planned states, as these typically resist change in order to protect vested interests. No economy operates with perfect efficiency, however, and even competitive market economies can

be slow to adapt to particular changes, such as those that require innovative approaches to work. For example, a number of companies had already found that remote-working practices improved productivity and reduced costs, but they were not widely adopted until the Covid-19 pandemic forced companies to overcome their organizational inertia and implement the necessary changes.

The histories of human societies, which are very complex systems, show periods of relative stability and instability. For example, a society in which numbers and demands are low relative to available resources, and in which the area ecology has absorbed the human impact while retaining the same essential characteristics is more likely to be ecologically stable than one that does not have these attributes, while a society that has a strong consensus on the distribution of power and resources is more likely to be politically stable than one that does not have such a consensus. Such attributes always vary over time, so that a society could become politically or environmentally unstable when some key element of political support fails or some critical environmental resource falls below the necessary minimum.

At national level, therefore, resilience is a highly complex, multi-layered concept, with basic survival needs (food, water, energy etc.) at the base, but with overlays of political, social and economic criteria. So ideas of societal resilience can include core cultural values and beliefs, social stability, economic productivity, and the ability of the ecosystem to supply food and water, absorb wastes and other key ecosystem services. In practice, all of these criteria vary over time, which means that the pace of change is also important. Social and cultural changes that happen over several generations, for example, allow more time for people to adjust.

Carrying capacity is a crucial dimension of resilience. In ecology, it refers to the level of demand that a given ecosystem can support. The main factors in determining carrying capacity are levels of population, patterns of consumption and resource demand, environmental yield potential and resource flows, and environmental absorption capacity and impacts. The interaction of these factors determines the long-term viability of development options.

Although food supply is an obvious dimension, it is not the only potential limiting factor; pollution absorption capacity can also be a key determinant of carrying capacity. For example, if the rate at which carbon is added to the atmosphere exceeds the rate at which the carbon can be reabsorbed there will be an accumulation of carbon, which will reduce the rate at which heat is

lost from the atmosphere, which will in turn lead to thermal expansion of the oceans and a consequent rise in sea level, changes in weather systems and in the distribution of e.g. insect-borne diseases, and other factors that may start to impose increasingly severe costs. However, as this example suggests, carrying capacity is not a fixed, unvarying constraint. Technological progress can increase efficiency and productivity, develop substitutes for some resources, and allow wastes to be recovered and recycled, thereby changing the relationship between economic development and environmental impact.

It is also important to note that trade is a key part of the human ecosystem. The Earth's biological and mineral resources are not evenly distributed, but trade ensures the transfer of food, water, energy and other key resources into centres of population, effectively transferring carrying capacity. The efficiency of international trade and transport systems is also, therefore, a key determinant of human sustainability. Similarly, the viability of cities depends on the sub-systems of transport and trade that move people, goods, services, energy, food and water to their destinations, and ensure that wastes are removed and processed.

This is a particularly important consideration with regard to small island states, which typically rely on imports of energy, food, manufactured goods and other commodities in order to remain viable.

Urban resilience and climate change

The concept of resilience can go beyond preventing or mitigating asset loss caused by individual incidents, and focus rather on upgrading systemic performance in the face of all known hazards (Arup, 2014a: 3); (Dodman, Diep, & Colenbrander, 2017). This is also true of climate resilience, which can be used to describe adaptation at different scales: from specific investments in infrastructure or individual behavioural changes, to entire societies and economies (Dodman et al., 2009, Béné et al., 2014); (Dodman, Diep, & Colenbrander, 2017). Resilient societies will have sufficient ability to absorb impacts (or 'buffering capacity') to enable them to adjust to pressure without collapsing (Dodman, Diep, & Colenbrander, 2017).

Sub-characteristics and goals of a resilient system

Sub-characteristic	Desired outcome
Flexibility	Continuous interplay of evolution and adaptation
Bio- and social diversity	Multi-functionality and increased opportunities
Redundancy	Availability of extra resources and capacity in case of failure with other mechanisms
Modularity	Self-organisation
Safe failure	Minimum damage, key service delivery are maintained even under failure
Uncertainty and learning	Comprehension and anticipation, drawing from lessons
Resourcefulness and responsiveness	Rapid and adapted actions

For resilience theories to be practically useful, it is important to recognise the dynamic nature of systems. Béné *et al.* (2012: 23) propose a resilience framework focusing on three main components: "*resistance* in a period of small disturbance, *adaptation* in a time of greater disturbance, and *transformability* when conditions are becoming unviable or unsustainable" (Figure 3). This framework suggests three dimensions or stages of resilience depending on the nature and scale of the problem.

Diagram from *(Dodman, Diep, & Colenbrander, 2017)*

Characteristics of a Resilient City

The most important characteristics fall into a small set of categories. The main ones can be aggregated as leadership and strategy; infrastructure, resources and environment; health and welfare, social and economic organization. These are illustrated in the matrix below.

LEADERSHIP AND STRATEGY (KNOWLEDGE)
- Integrated development planning
- Effective leadership and management
- Broad range of stakeholders empowered

HEALTH AND WELLBEING OF INDIVIDUALS (PEOPLE)
- Minimal human vulnerability
- Diverse livelihoods and employment
- Safeguards to human life and health

INFRASTRUCTURE AND ENVIRONMENT (PLACE)
- Reliable communications and mobility
- Continuity of critical services
- Reduced physical exposure of natural and manmade assets

ECONOMY AND SOCIETY (ORGANISATION)
- Economic prosperity and availability of financial resources and contingency funds
- Social stability, security and justice
- Collective identity and mutual support within communities

Resilience and adaptation to climate change

Adaptation to a complex multi-impact challenge like climate change can be defined as an adjustment in social and economic systems in response to changes (or expected changes) in climate in order to mitigate adverse effects or to capitalize on new opportunities (IPCC, 2001). That typically requires both building capacity and implementing policy and planning decisions, which will tend to reflect a number of parameters, including:

- Current societal norms and processes (Adger, Arnell, & Tompkins, 2005)
- Available information technology (O'Brien & Leichenko, 2000)
- Market forces, (Smit, Burton, Klein, & Wandel, 2000)
- Social networks (Adger W. , 2003), and
- Actions taken by individuals and organizations to achieve their own goals.

Human societies have always had to cope with variations in e.g. rainfall or temperature, and adaptation measures have ranged from migration and transhumance in semi-arid pastoralist societies to financial insurance systems in developed countries. Vulnerabilities and responses are determined not just by the impact but also by the wealth of society and the ability to mobilize additional resources.

Climate vulnerability includes the susceptibility to stressors, mitigated by the ability to respond effectively to stresses (Mertz, Halsnæs, Olesen, & Rasmussen, 2009). Climate vulnerability resolves into three areas: *risk exposure, risk sensitivity* and *adaptive capacity,* where *climate exposure* refers to the people and physical assets threatened by extreme weather events, *risk sensitivity* refers to the extent of the impact, and *adaptive capacity* ranges from basic access to essential resources to advanced mechanisms such as evidence-based policy formation and coordinated delivery methods (Cárdenas, Bonilla, & Brusa, 2021).

For example, s*ensitivity* will tend to be high in systems that include settlements built on flood plains, hill slopes, or low-lying coastal areas, while *adaptation* may take the form of reducing reliance on vulnerable systems, such as diversifying food production away from a limited number of drought-prone crops, decreasing sensitivity by avoiding building settlements and infrastructure in high-risk locations, or strengthening existing infrastructure so that it less likely to be damaged by unusual events (Huq, Adger, Brown, & Hulme, 2003).

Sensitivity to climate change, like vulnerability to danger, overlaps with but is not synonymous with poverty (Cannon, 1994). It is the poor, however, that are most immediately and obviously exposed to the various hazards of climate change (Kates, 2000).

Building resilience: country case studies

The countries that appear to be on track to build societal resilience have strong policy frameworks aimed at eventual carbon neutrality (Somvichian-Clausen, 2020), supported by political stability and the economic resources needed for the necessary investments. Other countries, such as Fiji, Tuvalu and the Marshall Islands also have ambitious policy goals, but their ability to achieve them is circumscribed by their relative lack of resources. The former group includes the following:

Norway

Norway filed its revised Paris Agreement target in 2020, aiming to reduce emissions by at least 50 percent below 1990 levels by 2020. Norway also maintains a lead in terms of electric vehicle sales, with a record 42 percent of all vehicles sold in the country in 2019 (Somvichian-Clausen, 2020). Some of the other relevant actions taken by Norway are:

- Putting into effect the Paris Agreement, the UN Sustainable Development Goals, and the Sendai Framework for Disaster Risk Reduction.
- Lowering Norway's greenhouse gas emissions by 40 percent by 2030
- Supporting climate change efforts through the Green Climate Fund (GCF), the Global Environmental Facility (GEF), the World Bank, and other multilateral funds and partners
- Spearheading international initiatives in the fields of health and climate change
- Encouraging the phase-out of fossil fuel subsidies
- Promoting sustainable urban development and renewable energy development
- Contributing to the sustainable management of marine resources (Climate Change and the Environment, 2020)

New Zealand

New Zealands's wealth is heavily reliant on natural resources. Agriculture, wood products, fishing, and tourism are all essential to the economy, and over 80 percent of these exports are vulnerable to climate change (Somvichian-Clausen, 2020). However, strong social welfare and low levels of corruption and abuse of power in government will help to maintain social cohesion during the impacts of climate change. New Zealand passed legislation in 2019 to establish a net zero goal for all greenhouse emissions by 2050 (with the exception of biogenic methane, primarily released by sheep and cattle, reflecting the importance of the agriculture sector).

Figure 2: 2017: New Zealand considered issuing a special visa for Pacific Islanders displaced by climate change (Dempster & Ober, 2020)

Finland

Finland's climate policy is a two-pronged strategy, reducing greenhouse gas emissions while developing a bioeconomy. The Climate Change Act aims to reduce emissions by a world-leading 80 percent by 2050, with goals for 2030 focusing on transportation, housing, and agriculture (Somvichian-Clausen, 2020).

Figure 3: Helsinki Central Library, Finland. (photo: Tuomas Uusheimo)

The country's vast forestland and renewable biomass reserves have become a major focus for energy production in the coming decades, with wood-based energy accounting for over 25 percent of total energy consumption. Finland has also launched a Cleantech project, which

encourages sustainable consumption, manufacturing, and innovation (Somvichian-Clausen, 2020).

Denmark

Denmark's 2019 climate bill also set aggressive targets, aiming to reduce carbon emissions to 70 percent of 1990 levels by 2030, and carbon neutrality by 2050 (Somvichian-Clausen, 2020). As a small country, Denmark itself has a small carbon footprint, but is committeed to ensuring the following:

Figure 4: One of the world's largest offshore wind farms, Middelgrunden, located in Oeresund, Denmark, near Copenhagen harbor.

- Increased global climate ambition: persuading states and non-state entities to commit to ambitious goals that will help to minimize global warming; collaborating with other states, multilateral organizations and civil society on ambitious climate adaptation, resilience, and sustainable development measures.
- Reducing global greenhouse gas emissions: to work towards a worldwide green transition centered on decreasing emissions from the major sources and promoting sustainable development in underdeveloped countries.
- Increased emphasis on adaptation and long-term development: encouraging resilience and adaptation efforts with a climate-focused development cooperation focused on the world's poorest and most vulnerable developing countries, sharing Danish preventative and adaption methods.
- Shifting financial flows from red to green: moving global financial flows away from fossil fuels and toward green, climate-friendly investments; advocating the greening of financial and energy markets and systems that encourage investments in renewables; working to improve climate finance mobilization for the poorest and most vulnerable countries.

- Cooperating with the private sector on green solutions: collaborating with the private sector to promote green Danish solutions to support successful global climate action in other countries (MFAS, 2020).

Sweden

Sweden's climate goals include reducing overall emissions by 59 percent compared to 2005 levels by 2030, with domestic transportation emissions lowered by 70 percent by the same year (Somvichian-Clausen, 2020). Sweden's 2017 climate policy framework sets out the following goals:

- Net zero greenhouse gas emissions into the environment by 2045, followed by negative emissions.
- Domestic transportation emissions, excluding domestic aviation, decreased by at least 70 percent by 2030 compared to 2010.
- By 2030, emissions in the sectors covered by EU Effort-Sharing Regulation should be at least 63 percent lower than in 1990.
- By 2040, emissions in the sectors covered by the EU Effort Sharing Regulation should be at least 75 percent lower than in 1990.

Examples of cities in transition

Some cities are becoming test-beds for more sustainable futures (Loorbach & Shiroyama, 2016). Here are some examples of cities in transition.

Smart cities

The definition of smart city is 'the effective integration of physical, digital, and human systems in the built environment to offer a sustainable, prosperous, and inclusive future for residents.' (Arimah, Jensen, Mutizwa-Mangiza, & Yemeru, 2009) The smart city concept involves using ICTs in infrastructure, building design and operation, transport, waste and other aspects of city management. This allows real-time data collection to improve governance, model and track urban development, manage infrastructure, monitor the environment and natural resource flows, and engage communities. The latest iterations of smart cities have started to leverage the Internet of Things (IoT), big data, and cloud computing technologies to develop links between each component and layer of a city (Kirimtat, Krejcar, Kertesz, & Tasgetiren, 2020).

Some of the dimensions of the smart city concept are as follows:

- **Smart Economy**: Having the policies and infrastructure to support always-on information, trading and mobile commerce for goods, services, real estate, shares etc.
- **Smart Governance**: The provision of city services, information channels, access to city councilors and officials, decisions and participatory discussions are important features of the governance of smart cities;
- **Smart Mobility**: Smart cities are looking at innovative ways to manage urban congestion. The Internet of Vehicles (IoV) can underpin intelligent transportation system and support other Apps, such as a Hybrid Emergency Message Transmission (HEMT) system to improve traffic safety.
- **Smart Environment**: Air quality, green and water areas, pollution monitoring, trash management, energy efficiency, and city trees can all now be monitored, and integrated with other city management systems. For example, air quality monitoring can be overlaid with traffic monitoring to allow the automated implementation of traffic calming or other pollution reduction measures.
- **Smart Living:** smart buildings can be used to reduce waste and improve public health and safety (Kirimtat, Krejcar, Kertesz, & Tasgetiren, 2020)**.**

Singapore

Singapore is one of the world's smartest cities, consistently in the top 10 of the IMD rankings (NEC, 2022). Singapore is the world's second-most densely populated city. They collect data across the city utilizing sensors. The sensors capture information about what citizens do on a daily basis, and can measure everything from the cleanliness of a certain region to the crowd level at an event (NEC, 2022). Singapore also plans to become a vehicle-free eco-smart metropolis. The proposed ‘forest city’ to be built in Tengah in Singapore's western region will include five residential districts with 42,000 dwellings, as well as safe zones for both walkers and bikers (NEC, 2022).

New York

Hundreds of smart sensors have been installed around New York City's districts as part of the city's smart city pilot project which started in 2020, and the city is building out WiFi networks.

Oslo

Oslo has over 650,000 LED lights connected to processing stations throughout the city which modify the quantity of lighting based on needs. All city vehicles will be electric by 2025, and the city is monitoring cars with license plate scanners to assess traffic movement around the city and develop a data-driven method to reduce traffic congestion (NEC, 2022).

London

Over the last decade, London has established a variety of smart city programs, led by the Office of Technology, which is dedicated to making London a smart city (NEC, 2022). Their Civic Innovation Challenge aims to assist entrepreneurs and start-ups in developing answers to urban concerns. Connect London seeks to deliver 5G connection and fiber-optic coverage throughout the city. As part of London's efforts to reduce emissions and traffic congestion, the lampposts will be retrofitted with sensors and electric vehicle charging stations (NEC, 2022).

Copenhagen, Denmark

Copenhagen ranked seventh on the IMD's ranking of smart cities in 2021 (NEC, 2022). The Copenhagen Solutions Lab developed a system in 2017 for monitoring air quality, energy consumption, transportation, and trash management. The system also combines parking systems, traffic signals, buildings, smart metering, and electric vehicle charging systems to control traffic in real time (NEC, 2022). In addition, the city is collaborating with the Massachusetts Institute of Technology (MIT) to create a smart bike system for the city. The city is working to integrate all of these smart technologies into a single platform in order to provide a more efficient transport system for the city.

Sustainable Cities

Reykjavik, Iceland

Reykjavik intends to eliminate greenhouse gas emissions by 2040 by encouraging walking, cycling, and the use of public transportation. The city intends to continue deploying hydrogen buses, despite the fact that just 4 percent of people utilize them. The city intends to triple this figure by 2030. In addition, the city has invested millions in the construction of bike paths and is encouraging the 9,000 public employees to drive electric vehicles by providing free parking and lower taxes (Lux, 2021).

Vancouver, Canada

Vancouver has the Greenest City program and the lowest greenhouse gas emissions of any large city in North America (Lux, 2021). There has been a 23 percent increase in green occupations and a 26 percent increase in local food jobs since 2013 (Lux, 2021).

Cape Town, South Africa

Cape Town has a goal of obtaining 10 percent of its energy from renewable sources (Lux, 2021), has invested on secure bike lanes, and the My CiTi fast service allows bicycles to be carried on buses without charge (Lux, 2021).

Urban transport

Most cities today developed around the car. Many people live in one area, commute to work somewhere else, and go shopping in a third. This increases demand for vehicles and gasoline, generates congestion and air pollution, and consumes millions of hours lost while sitting in traffic.

Melbourne, Portland, Paris, Ottawa, Bogota, Seoul, Barcelona and other cities are now implementing city plans to allow everyone to get everything they need within twenty minutes walking distance, including work, shopping, business services, education, community facilities and recreational resources. The goal is to reduce the time lost in traffic congestion, reduce the consumption of gasoline and give people cleaner air and a better quality of life.

The Covid pandemic created another reason to reduce the need to use cars in cities. Many organizations were forced to move to a more distributed model of working during the pandemic, but have realized major gains in terms of cost, time, worker engagement and customer satisfaction. Companies such as British Airways, Siemens, Capital One and State Farm have therefore said that they are not going back to an office system, but will operate mixed-mode or wholly online from now on. As a result, many cities are now rethinking building regulations and the management of transport demand. As firms move online, office buildings and car parks are going to be repurposed, which will open up more development opportunities and public spaces in cities, and new-build homes are being redesigned to include workspaces and places where children can study, which will reduce the number of car journeys.

The cities that have reduced the use of cars have seen increased use of public transport, but crowded public transport systems can increase the risk of transmission of a droplet-borne virus. So it is important to upgrade the ICT infrastructure at the same time, as that will support the transition to a digital society and economy where most transactions do not require a physical presence. As noted above, most of the cities with urban resilience strategies are also becoming smart cities.

Floating cities

The concept of floating cities arose as another response to rising sea levels and land constraints (Kirimtat, Krejcar, Kertesz, & Tasgetiren, 2020). Ancillary attractions include access to renewable resources of water and solar energy and aquaculture (Huynh, 2019).

The concept is not new; floating villages can be found in Cambodia, Vietnam, Thailand, Indonesia, China and Bolivia.

Figure 5: The city can organically transform and adapt over time, evolving from a neighborhood of 300 residents to a city of 10,000. Thirty-six 2-hectare floating neighborhoods and dozens of productive outposts create a vibrant community that can expand and cont

Cambodia

The floating villages in Cambodia are in Siem Reap district, used by fishing communities (Ko, 2015). The floating villages are small wooden dwellings or tents built on a wooden base.

Figure 6: The Eerie Beauty of Cambodia – Tonle Sap

Venice, Italy

Venice is built on 118 small islands linked by 150 canals and 417 bridges. It was first inhabited in the 5th century A.D. by the Veneti.

Floating cities as a climate change solution

Figure 7: These small, low-density pods are currently under construction in the Linton Bay Marina on the north coast of Panama (Hardingham-Gill, 2022)

New concepts for floating cities include such ideas as building them in modular format, as connected platforms with varied functions, imposing height restrictions in order to maintain stability and reduce damage from climate events, using desalination systems and collectors to extract potable water from the sea, and collecting and purifying grey water, supplemented by atmospheric moisture extracted using dehumidifiers (Huynh, 2019), to meet water demand.

Almere, Holland

The city of Almere was founded in the 1970s on land that was formerly the Ijsselmeer, a saltwater lake that used to be part of the North Sea. The lake was formed when its connection to the sea was cut off by a 32km causeway built in 1932. Almere sits on an artificial island, Flevoland, about 1,000 km² in size (Miller, 2022).

One of the reasons for building Almere was to avoid further overcrowding in Amsterdam and Utrecht. It is now the eighth-largest city in Holland, with a population of 200,000. It has over

40km of coastline and 400km of dedicated cycle paths, which allow almost all the residents to live within five minutes of parks, paths and public transport. About 60 percent of the city area is in urban agriculture, which reduces food miles.

The city was designed with a participatory, interactive model of urban planning. Groups of locals and other stakeholders (city planners, farmers, legal experts, and the Dutch national water board) used a collaborative planning tool to make choices about land use and infrastructure, while incorporating good water management and other principles.

Figure 8: The city of Almere[1]

[1] Image credit: Pavlo Glazkov/Alamy, BBC

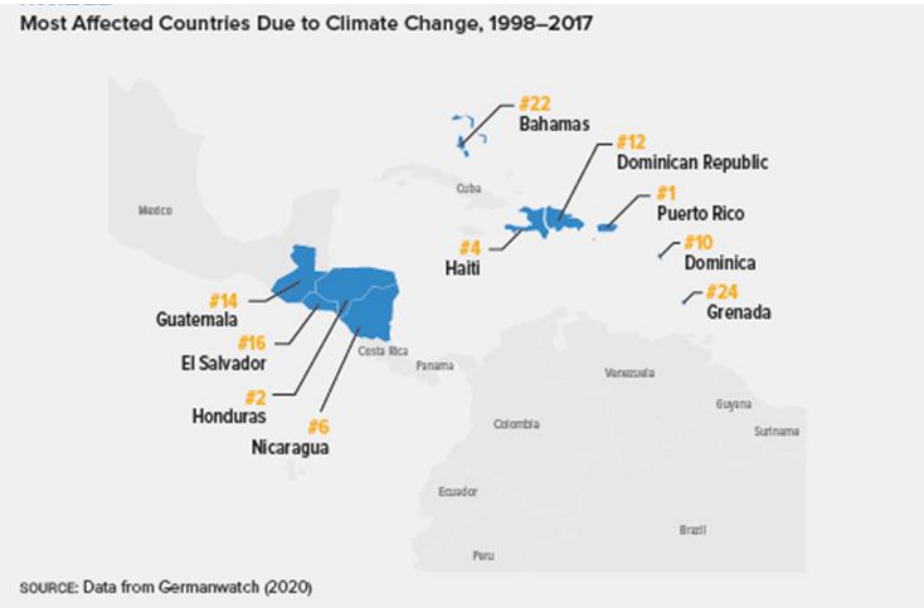
3. The Caribbean region

The Caribbean region is 2.7m km², of which 91.3 percent is marine territory. The population of 43 million is distributed across 7,000 islands, cays and 3 mainland states (Belize, Guyana and Suriname), organized into 30 different political entities (12 independent states, 18 dependent territories), speaking 4 primary languages (English, Spanish, Dutch and French) and a number of patois, and containing some of the richest (Cayman) and poorest (Haiti) countries in the world.

Most of the Caribbean nations have a high percentage of total capital stock exposed to hazard, as many of the urban centres are located on coastal plains, including residential and business areas, government buildings, wharves and airports, so a single severe weather event could potentially impact the centres of governance, the greater part of the population and much of the economic and transport infrastructure simultaneously. Any increase in the frequency or severity of hurricanes and floods would also make it significantly harder to recover between storms. The Bahamas, for example, were impacted by Category 4 hurricanes in three consecutive years (2015-2017); the storms damaged schools and houses, tourism, fisheries, health, water and sanitation facilities, roads, ports and airports, power and telecommunications infrastructure, and cost 6 percent of gross domestic product (GDP). This was then followed in 2019 by a Category 5 hurricane that went over Abaco and Grand Bahama islands and left 74 confirmed dead, 200 missing, 70,000 homeless and damage estimated at 25 percent of GDP. If the hurricane had gone over New Providence Island instead it would have destroyed part of Nassau, the capital, the centre of business, government, administration, law, media and education, and home for 70 percent of the population of The Bahamas, and crippled the country's ability to respond or recover.

The 2017 Hurricane Season caused severe destruction on several islands, resulting in a US$741 million reduction in tourism revenue (World Travel & Tourism Council, 2018). In September 2017 Hurricane Maria, a category five hurricane, damaged over 90 percent of the infrastructure in Dominica, and the water and electricity public utility systems collapsed. Shortly after Maria, Hurricanes Irma and Jose impacted Antigua and Barbuda, Anguilla, the British Virgin Islands, Saint Barthélemy, The Bahamas and Turks and Caicos Islands.

The impacts of climate change will be non-linear, which means that the consequences for Caribbean nations will escalate as the temperature continues to rise. A rise of 1.5°C would expose about 14 percent of the world's population to extreme heat-waves at least once every five years, but a rise of 2°C would increase that to 37 percent of the world's population. Similarly, while a rise of 1.5°C would result in a sea-level rise of 0.1 metres; a rise of 2°C would give a sea-level rise of 0.2 metres, at which point over 70 percent of the world's coastlines would be affected by coastal flooding, beach erosion and salinization. The impacts of climate change will also be unevenly distributed; in the mid-latitudes the hottest days will be up to 3°C hotter if the world average rises by 1.5°C and up to 4°C hotter if the world average rises by 2°C (Buis, 2019). Much of this is now inevitable; surface temperatures will continue to rise by at least another 0.6 degrees C even if carbon emissions were stabilized at the current level because of the thermal inertia of the oceans[2].

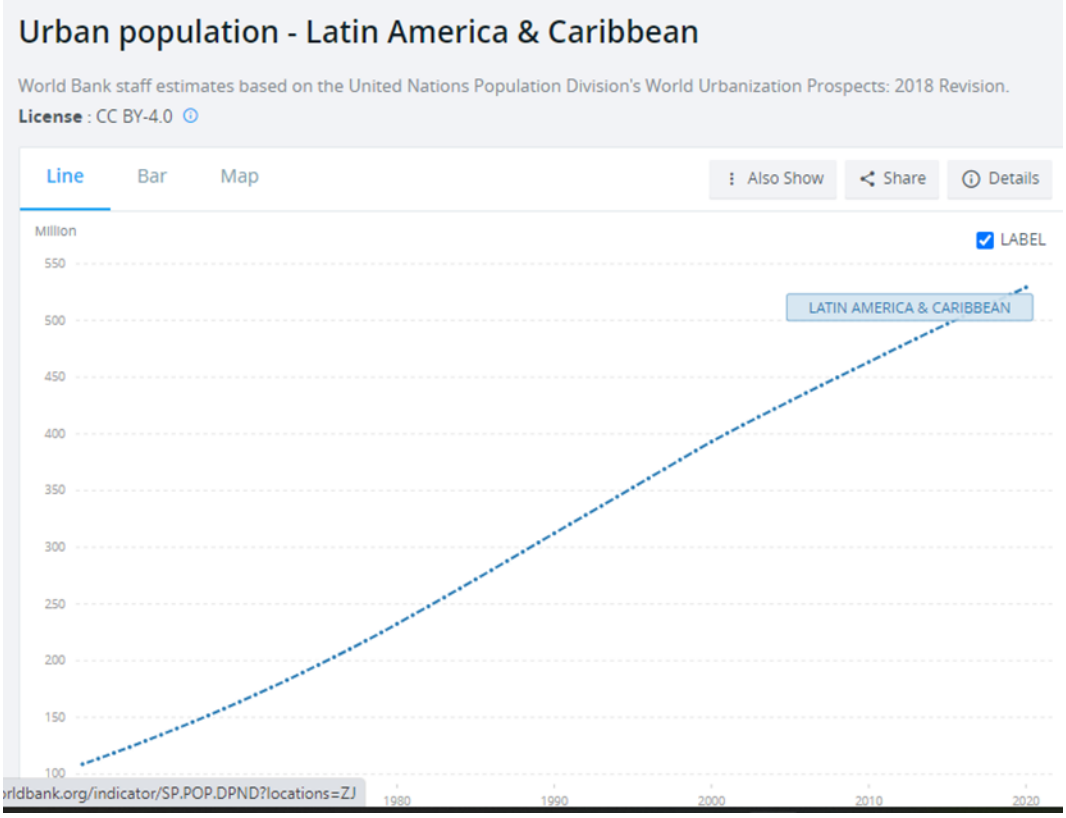


The Caribbean region is still in the early stages of post-COVID recovery. Tourism receipts have been sharply reduced for two years, government revenues have declined and public debts have risen, in several cases to over 100 percent of GDP.

[2] The oceans have about 500 times the mass of the atmosphere, so take longer to heat.

Food and energy security is also an increasing concern. Russia is one of the three largest producers of oil and gas; Russia and Ukraine between them supplied about 30 percent of global wheat exports and 20 percent of corn exports; Russia and Belarus accounted for more than 40 percent of global exports of potash; and Russia supplied about 22 percent of global exports of ammonia, 14 percent of urea exports and about 14 percent of monoammonium phosphate, all of them vitally important fertilizers (Polansek & Mano, 2022). The war therefore has serious implications for global supplies of oil, gas, grains and fertilizer. Most Caribbean nations are heavily dependent on imported fuel and food; several import over 90 percent of their food. Rising food and energy costs will drive up inflation and delay post-Covid economic recovery. A number of Caribbean economies are therefore now fragile, and will have to adjust to both the disruptive shocks in energy and food markets caused by Russia's invasion of Ukraine and the multiple impacts of climate change from an exceptionally weak position.

Caribbean urbanization



The Caribbean has a long history of urban dominance by its main port towns, many of which were founded in the sixteenth and seventeenth centuries, but the region has only experienced rapid rates of urban growth since the end of World War II. Currently, slightly more than half of the West Indian population lives in cities. This is higher than most parts of the less developed world (Boswell, 1991). Population growth in the Caribbean has largely been an urban phenomenon (Jaitman, 2015).

Figure 9: Castries, St Lucia: the main urban centres of most Caribbean countries are on coastal plains; much of the infrastructure is exposed to rising sea levels.

The rapid urbanization in Latin America and the Caribbean is creating potential future problems; the Inter-American Development Bank (IDB) report 'A Blue Urban Agenda: Adapting to Climate Change in the Coastal Cities of Caribbean and Pacific Small Island Developing States cities in Small Island Developing States' notes some 4.2 million people in Caribbean and Pacific Small Island Developing States now live in locations prone to floods owing to rising sea levels.

Buildings and energy use

The world's buildings require vast amounts of energy to construct and operate. Combined, building construction and operation represent 25 percent of the world's total power demand. Construction contributes about 11 percent of the world's carbon emissions, while operational losses from inefficient buildings contribute about 28 percent. So any significant improvements in efficiency in construction and operation would substantially reduce both the global demand for energy and the world's carbon emissions.

Almost all construction in the Caribbean today is based on cement and steel, and each of these industries contributes about 8 percent of total world carbon emissions. Combined, these two industries are second only to the fossil fuel industry as the world's largest source of carbon emissions.

It is therefore important to develop new construction materials and new building forms which will have lower levels of embodied carbon and also give lower carbon emissions in operation. There are a range of candidates, including cross-laminated timber, which can have the structural strength of steel, resists warping, allows buildings to be rapidly assembled from prefabricated sections and gives sufficient flexibility to allow the building to withstand an earthquake or hurricane; bamboo strand lumber, plywood or laminates, which have high density and tensile strength, and are water and weather-resistant; and eco-composites, natural fibres in a biological matrix derived from plant starches or tree resins. The use of engineered timber, bamboo and eco-composites would offer completely new prospects for local agriculture. There is an immense potential market for such industrial crops, many of which grow in sub-tropical regions, and could be competitively processed and manufactured in developing countries. This would allow local farmers and processors to become suppliers of building materials for the world.

Another reason why the construction industry currently has such a high environmental impact is that the industry involves demolition as well as construction, with a large part of the material from demolitions going to dumps and serving no further purpose, which means that most of the high energy-cost materials are effectively single-use. However, there are now prototypes of buildings that are made entirely from natural materials and fully demountable, which means that

every component can be disassembled and then reassembled into a new configuration. In future, many buildings could be leased, rather than owned; tenants would move out when their needs changed, and the building would be reconfigured for the next tenant. The current planning framework for London, for example, specifies that all new applications for planning permission must include a Circular Economy Statement that explains how the building components can be disassembled and reused.

With regard to building operation, levels of energy efficiency in most buildings in Jamaica are low. They have high thermal mass, few are designed to minimize unwanted heat gain or utilize passive cooling solutions, so they require cooling in order to remain at a tolerable internal temperature. However, this means that the building sector has considerable potential to become far more efficient in terms of resource use, less environmentally intensive, and less costly.

Net Zero/Energy-Plus buildings represent the most advanced solution to date; highly efficient buildings that generate at least as much power as they consume. Net Zero buildings are designed to maximize energy efficiency, using orientation and insulation to minimize unwanted heat gain or heat loss, maximizing the use of sunlight for lighting, natural ventilation for cooling, and using energy-efficient appliances to reduce the need for air conditioning. Energy-Plus buildings generate more power than they can use, so the owners can sell it to the grid. This model has been working since 2008 in Freiburg, Germany, where apartment complexes earn money for their owners by exporting power. If this approach was widely adopted, many of the world's power stations would become redundant, while electricity grids would no longer be one-way transport systems, but dynamic markets in which customers were also suppliers, buying and selling power to each other. Energy-Plus buildings could eventually make cities net exporters of power.

This approach is becoming even more attractive as alternative sources of power become increasingly competitive. It is now about 50 percent cheaper to generate electricity from renewables compared with fossil fuel plants, partly because fossil fuels are no longer competitive when environmental costs and subsidies are included, and partly because about two-thirds of the energy from fossil fuels is wasted, lost in mining, drilling, burning, converting, transmitting,

using and waste disposal. Renewables involve no extraction, no combustion, fewer conversions, and so have much lower losses.

With sufficient policy push, renewables could be the largest source of power by 2050, mostly from hydropower, wind and solar. Solar is growing particularly rapidly. Solar-produced electricity has fallen dramatically in price; it is already 20-50 percent cheaper than in 2019, which means that it is now the 'cheapest electricity in history'. The development of perovskite solar cells, which promise to be both cheaper and more efficient than silicon, will bring substantial further cost reductions.

Changes in government policies could significantly shorten the transition. The most important change would be removing the global subsidies for fossil fuels, currently over US$300 billion/year. In some countries, the capital cost of solar cells and energy efficiency technologies is still a deterrent, so Governments could accelerate the transition to renewables by zero-rating the relevant items.

Figure 10: A Net Zero Energy Building at the University of the West Indies in Jamaica.

In many developing countries, improving energy efficiency in building construction and operation would reduce energy imports, minimize exposure to energy price volatility, increase levels of disposable income, improve the balance of payments, enhance competitiveness, increase the number of investment opportunities, raise levels of disposable income, reduce the national contribution to climate change and support sustained economic growth. Reform of the built environment would therefore have substantial long-term benefits for these countries.

Housing and urban infrastructure in Latin America and the Caribbean

Harvard HouseZero - A Retrofit Response to Climate Change (Walsh, 2017)

The challenge now is to incorporate climate change considerations into building design and spatial urban planning decisions in ways that provide co-benefits for adaptation and mitigation. Innovative approaches, such as combining ecosystem-based and structural adaptation responses, will be required to reduce adaptation costs and provide multiple benefits across flood control, sanitation, water resource management, landslide prevention, and coastal protection, all of which are critical adaptation options for Caribbean cities (Wilkinson, et al., 2022).

At present, a lack of water and sanitation services is one of the major housing gaps in Latin America and the Caribbean urban areas: with over 21 million families living in houses that lack at least one essential utility. The most common primary infrastructure issue is inadequate sanitation, which affects 13 percent of homes (almost 17 million). Piped water is unavailable to around 8 million dwellings (and the quality of the water received by most households is sub-optimal). The urban poor are disproportionately affected: in 2009, the proportion of poor families lacking infrastructure was six times that of high-income households. While high-income families

have essentially no overcrowding or poor-quality building materials, these issues afflict 16 percent of urban poor households (Jaitman, 2015).

The Caribbean is widely perceived as a sort of island paradise, but the reality is that the majority of Caribbean islands are highly urbanized areas with similar infrastructure, solid water management, and public health challenges as other urban zones in Latin America, albeit on a smaller scale (Frojmovic, Graeff, & Mohammed, 2013). In addition, the majority of the population of the islands is concentrated around the coast. According to UNEP (2008), around 70 percent live in coastal towns, with more than 50 percent living less than 1.5 kilometres from the coast, which increase the risk that a single serious weather event could result in a relatively large proportion of the population becoming environmental refugees. The risk is being compounded by the fact that almost 70 percent of Caribbean beaches are eroding at rates ranging from 0.25 to 9 metres per year (UNEP 2008). This makes in particularly important to adapt and strengthen the resilience of cities in SIDS coastal zones, particularly those experiencing increasing urbanization. SIDS can reduce their exposure to risk by implementing strategies to mitigate urban climate change (Mycoo & Donovan, 2017).

Energy use in the Caribbean

Most of the Caribbean island nations are heavily dependent on imported energy and food; in some cases for over 90 percent of both. The region's long-standing reliance on fossil fuels has resulted in citizens paying some of the world's highest energy prices. This indicates the extent of the lock-in around old solutions, as the region has significant renewable energy potential (mainly solar and wind).

In 1999 the Government of Jamaica increased gasoline tax by 30 percent, effectively a small reduction in the concealed subsidy to fossil fuel use. This triggered three days of civil unrest and rioting that resulted in the deaths of nine people, and the Government was obliged to cut the increase by nearly half. This demonstrated the risk of abrupt changes in energy policy, and the fact that citizens are frequently opposed to energy subsidy reforms (Hallack, 2022).

To attain a more diverse and sustainable energy mix, the region will therefore need to reform legal and regulatory frameworks to encourage the private sector to participate in these projects, either directly or through public-private partnerships. Several Caribbean countries have already begun to implement such reforms, paving the way for a more sustainable energy future. Jamaica initially focused on LNG to diversify the energy mix (Yepez, 2016), but is now concerned to move to renewables.

A change in policy direction to encourage the development of energy efficiency and renewable energy would also have to be translated into sector-specific goal for e.g. improving transportation sector performance, reassessing the process of water transportation and distribution, addressing the complex nature of the water-food-energy nexus, heating and cooling in the built environment, and improving efficiency in consumption behaviors and production patterns (Quarless, Voccia, Balgobin, Bello, & Marcano, 2016).

Figure 11: Photo: IDB Sustainable Cities, Solar energy project in Jamaica

There are a number of ways that Caribbean Governments could increase energy efficiency, switch to renewables, and decarbonize their economies:

- Encouraging energy efficiency is often more cost-effective initially than developing new energy sources, so governments could, for example, reduce import duties on energy-saving technologies to encourage the replacement of energy-inefficient items.
- The issue of financing for new energy sources is one of the most significant challenges. Caribbean energy markets are small, and some have high levels of electricity theft, which erodes profits and makes investment unattractive. In Jamaica, for example, about 64 percent of the electricity consumers are registered and paid up to date, 15 percent are

registered but in arrears, and 21 percent are unregistered electricity thieves. This level of loss represents the greater part of the utility's profits, which drains the capital needed for investment.

- Governments can assist utilities to address the problem of theft, in part, by reforming the regulatory system. In Jamaica, for example, the current regulatory regime makes the problem significantly worse. The regulator fines the utility because it is concerned to protect the paying customers, whose electricity bills include a surcharge to cover the cost of the losses (the penalty is intended to spur the utility to take action to reduce the losses). The OUR has been applying this sanction every year since the electricity utility was privatized and the current regulatory regime was put in place, which was twenty years ago, but without success. The problem is that the regulator is pursuing a traditional strategy of direct regulation expressed in terms of specific single-issue compliance targets. This is a relatively inflexible and unresponsive model (it is designed to have those characteristics). There are other models of regulation, including approaches that have been used successfully to solve complex social/technical problems. A comprehensive response model with more interactive goal setting would help to resolve the current impasse.
- Many renewable energy projects cannot benefit from economies of scale because domestic demand is also small, limiting incentives for development. Regional interconnection could help to achieve economies of scale, lower operating costs, incentivize investment, and strengthen the energy market.
- The Caribbean Development Bank and the Inter-American Development Bank are funding a $71 million Sustainable Energy Facility for the Eastern Caribbean. The goal of the program is to diversify the energy mix in the six Eastern Caribbean countries, lowering the cost of power generation and electricity bills (Yepez, 2016).

Water Security in the Caribbean

Water security in the Caribbean has improved very substantially in the last 50 years, in spite of occasional natural disasters. However, there are still a number of challenges:

- The macroeconomic conditions are difficult; making it harder to generate the revenue needed for re-investment in the infrastructure

- Climate change is becoming a pressing issue.
- Leakage in the pipes, illegal connections, illegitimate hydrant use, wastes at public standpipes and off-grid use (including local sources of water; streams, wells and rainwater harvesting) are all common across the Caribbean region (Karanjac, 2003), and many consumers in some Caribbean nations are not metered. This combination means that much of the water is not accounted for. Jamaica loses about 60 percent of the water in the pipes to leaks and theft, while Trinidad loses about 36 percent.
- Most of the water utilities in Caribbean nations also have problems with collecting and making effective use of data for system management. There is little tradition of forward planning, although Jamaica has now developed a National Water Plan.
- The diverse pattern of European settlement in the Caribbean resulted in varying legal arrangements for water management, but water services were traditionally provided by island governments as a municipal or government obligation. Such arrangements lasted well into the post-colonial era (Cashman A. , 2012). After independence, however, most countries centralized water sector administration, partly to remedy a legacy of relative neglect and marginalization of substantial segments of the population based on race and colour (similar remedial measures were applied in health care and education). Most governments in the region took a strong social welfare attitude; the state played a major role in the economy and acted as a guarantor of critical services, with water being the prominent example (Portes, Dore-Cabral, & Landolt, 1997).This is why some Caribbean countries have been reluctant to privatize water services; which has had the unfortunate effect of starving the sector of capital and technology, and there is a widely-held perception that free water is a form of welfare, which has badly impacted revenues.
- The Caribbean has wide range of landforms—small, inhabited islands with a few thousand inhabitants, larger islands with populations in the millions, such as Cuba (Cashman A. , 2013) and several mainland states; some are flat and others have mountains of up to 3,000 meters. So there are a wide range of engineering challenges involved in delivering water.
- Many Caribbean countries are now facing additional challenges with rising food prices, declining agricultural sectors and climate change (Fletcher-Paul, Thomas, & Madramootoo, 2020), which means that the stress on water resources is likely to increase.

- The current institutional frameworks and enabling legislation are not focused on water security or on Integrated Urban Water Management. Although many governments see the need for change and have developed plans, existing efforts to put these plans into action have not been successful. Regional solutions have failed to gain traction, and national interventions have fared little better (Zafirakou, 2017).

With regard to future demands on the water system, they can be summarized as follows; the need to ensure that the supply is *adequate*, *physically accessible*, *assured* (i.e. that there are adequate resources to deal with shocks such as extreme weather events or security threats) and *affordable* (which includes issues such as the price of water in relation to disposable incomes in different parts of society, whether utility revenues allow full cost recovery, and the split between user revenue and taxpayer-funded support (Cashman A. , 2013)).

Progress towards water security in the Caribbean

The Caribbean states agreed to create IWRM plans and water use efficiency plans by 2005 at the Johannesburg World Summit on Sustainable Development in 2002, and a number of Caribbean nations have developed/drafted IWRM Roadmaps/Action Plans, including Antigua and Barbuda, Barbados, Dominica, Grenada, Guyana, Jamaica, The Bahamas, Trinidad and Tobago and St. Vincent and the Grenadines. The Sustainable Development Goal (SDG) Indicator 6.5.1 measures the level of implementation of IWRM by evaluating four essential components:

- Institutions and participation
- Enabling environment
- Instruments of management
- Funding

The Bahamas is one of the two Caribbean territories that have started the implementation of IWRM. The Bahamas is an archipelago of around 700 islands and 2,400 islets and cays located 50 miles east of Florida. They cover around 1,223 km². Only 30 of the islands are inhabited; most of the population live on New Providence (207 km²), where the capital, Nassau, is located.
The Bahamas is a water-scarce country, and water supplies are threatened by over-abstraction, mismanagement and pollution. The Water and Sewerage Corporation (WSC), which is part of

the Ministry of Public Enterprises, owns, operates, and manages 83 percent of the country's water systems, the private sector manages 17 percent.

The IWRM strategy being developed in The Bahamas tries to strike a balance between the need to protect and sustain water resources and the need to develop and use them. One of the key lessons to date was the importance of using an independent mediator to resolve conflicts between agencies and sectors (Secretariat, 2011).

Jamaica is technically a water-rich country but has serious issues with regard to groundwater contamination in areas such as the Liguanea Plain (the location of the capital, Kingston), mainly due to sewage disposal into soak-away pits, and soil erosion in areas such as the Rio Minho Watershed, driven primarily by deforestation and hillside farming operations (Birthwright, 2016). The lack of clarity about institutional roles has significantly reduced accountability for solving these problems (Birthwright, 2016). In 2013 the UK Department of International Development (DFID) funded the joint Effective Development of River Mining Project between the British Geological Survey and the Jamaica Mines and Geology Division with varying degrees of success (Birthwright, 2016).

Figure 12: Pathway of Jamaica towards IWRM Approach: Case Study of the Rio Minho Watershed in Clarendon

In Barbados, there is now just one remaining coastal wetland; the Graeme Hall Swamp. It has been designated as a Natural Heritage Conservation Area and has also been established as one of two Caribbean Coastal Marine Productivity Programme (CARICOMP) monitoring sites in Barbados. In spite of that, there are a number of problems with the Graeme Hall Watershed (467ha) in the south of Barbados; there are no adequate buffers to mitigate the effects of storm water from nearby residential, commercial, and agricultural areas on the quality of water in the wetland, and there is a risk of effluent discharge into the wetland from the nearby sewage treatment plant (Harold Lashley, 2016).

Overall, therefore, there has been little practical progress towards IWRM in the Caribbean, or towards reforming institutional frameworks (Cashman A. , 2017), so the majority of Caribbean nations are lagging on most or all of the SDG IWRM indicators. The 'Strategic Plan for the Caribbean Community 2015 – 2019: Repositioning CARICOM' does not directly address water management, indicating the lack of clear policy. Climate change is likely to increase the pressure on water resources in the Caribbean, making this gap even more salient.

The role of Caribbean cities in water management

Better urban development strategies could help to resolve some of these failings in the Caribbean.

> *"Urbanization brings opportunities for more efficient water management and improved access to drinking water and sanitation. At the same time, problems are often magnified in cities and are currently outpacing our ability to devise solutions."*
>
> - Ban Ki-moon, UN Secretary General, 2014 (Zafirakou, 2017)

At the national level general policies can be formulated to promote water conservation and prevent flooding, but real progress will require improvements in urban drainage, water storage and infiltration. separating grey and brown water and rainwater harvesting, and decentralized treatment of grey water and water storage ponds, denial of permits for construction in sensitive areas, and promotion of water-saving techniques and devices (Su, Gao, Guan, & Zuo, 2020), all of which can be more effectively implemented at local government level.

The three paradigms listed earlier; resilient cities, eco-cities and sponge cities all have characteristics that would support better and more sustainable water management in urban environments in the Caribbean.

The Blue Economy in the Caribbean

The World Bank and the United Nations Department of Economic and Social Affairs define the blue economy as the sustainable use of the oceans and coastal environment to gain economic benefits that support growing human populations and livelihoods (World Bank and United

Nations Department of Economic and Social Affairs, 2017). The blue economy includes tourism, fisheries and aquaculture, shipping and maritime logistics, construction and shipbuilding, mineral and oil extraction, pharmaceutical research and production, energy from wave-power generators, sea-bed turbines and offshore wind-farms, and scientific research, with particular regard to marine bioscience and biotechnology.

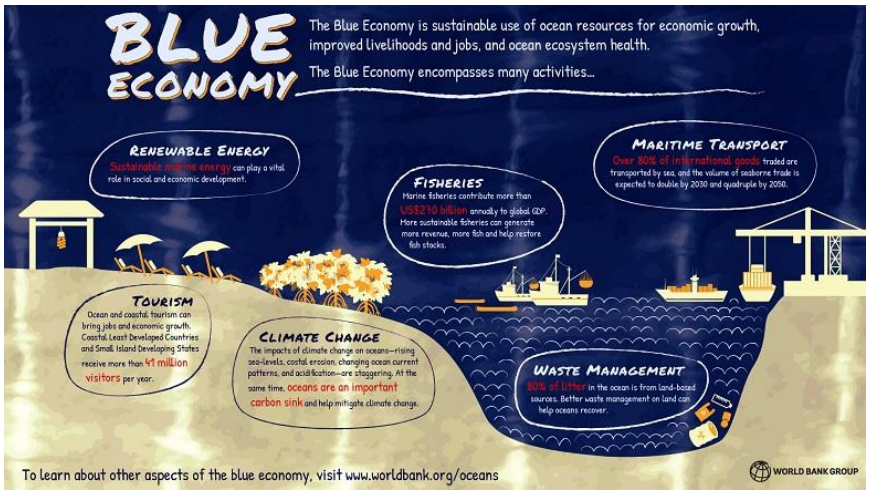


Figure 13. Sectors of The Blue Economy
Source: World Bank and United Nations Department of Economic and Social Affairs, 2017

The blue economy is critical to the future development of Small Island Developing States (SIDS). Some of the existing resources have been mismanaged and abused (specific problems include illegal, unreported and unregulated (IUU) fishing, a lack of monitoring and enforcement capacity and maritime domain awareness, sewage and fertilizer run-off, plastic pollution, coral reef death, loss of mangroves, beach erosion etc.), but these can in principle be remedied, and much of the potential has not yet been developed.

At present, the blue economy accounts for 15 percent of the region's GDP (World Travel & Tourism Council, 2018), about two-thirds of which is traditional fishing, with about 142,000 employed directly in the region (The World Bank, 2021) (Morgan, 2021) (Shortte, 2013). For some islands, however, the blue economy is the basis of their entire economy as it supports both shipping and tourism; shipping is essential to islands that import over 90 percent of their food, and tourism is the largest source of employment.

Wenhai et al. (2019) identified three economic perspectives on the blue economy (1) a means of addressing water shortages via desalination plants, (2) new opportunities for innovation and investment and (3) the development of the blue economy as a means to generate economic growth in land-based support services and downstream opportunities.

In 2018, the food import bill for fourteen CARICOM countries was $4.75 billion. At present, only Belize, Guyana, and Haiti produce more than half of their country's food (Ewing-Chow, 2019), all other Caribbean countries depend on food imports. This is not just for local consumers; a substantial part of the demand is generated by the tourism sector (BBC News, 2020). The development of mariculture (the farming of marine organisms for food and other products such as pharmaceuticals, food additives and nutraceuticals) and aquaculture (breeding, raising and harvesting fish, shellfish, and aquatic plants), along with the development of new intensive agricultural technologies could help to substantially reduce the dependence on imported food.

Aquaculture is an underdeveloped sector within the Caribbean. It could readily be scaled to produce over 34 million metric tons of seafood per annum in open sea and offshore facilities (CCRIF, 2019). In 2002, the Caribbean Regional Fisheries Mechanism (CRFM) was developed to support the sustainable use, management and conservation of the fisheries and aquatic resources of its Member States and to promote collaboration and knowledge share (Caribbean Regional Fisheries Mechanism (CRFM)). More recently, CRFM signed a partnership agreement with The Caribbean Catastrophe Risk Insurance Facility (CCRIF) to develop a climate-resilient and aquaculture industry throughout the region (CCRIF, 2019). Aquaculture is not risk-free; exposure to hurricanes remains a concern for potential investors. The CRFM and CCRIF project is therefore developing insurance for the aquaculture sector. This partnership also builds on CCRIF's existing Caribbean Oceans and Aquaculture Sustainability Facility (COAST), which is focused on providing a climate risk insurance structure to drive food security, protect the livelihoods, support the sustainable management of coastal infrastructure and fisheries, and to implement disaster risk reduction strategies (The World Bank, 2019).

However, ocean warming and acidification pose significant threats to the biodiversity of marine ecosystems, fisheries productivity, ocean chemistry and coral health, and ocean warming is likely to increase the intensity and frequency of climate hazards. This could have serious consequences for the future of the blue economy; many opportunities could be lost before they can be developed.

There are a number of international initiatives to conserve and protect the marine environment, including:

- 30x30 Ocean Campaign. The International Union for Conservation of Nature (IUCN), World Conservation Congress (2016). This campaign urges leaders to protect 30 percent of the oceans by establishing marine protected areas to safeguard marine biodiversity and ocean health and mitigate the impacts of climate change (PEW, 2021).
- The Clean Seas Campaign (launched 2017) is intended to encourage governments and citizens to address marine litter and plastic pollution by implementing legislation and community-based initiatives (Clean Seas). In response to the growing plastic pollution and call for action, twelve Caribbean Islands have now banned the use and import of select single-use plastics and Styrofoam products (St. Kitts Nevis Information Service (SKNIS), 2021).
- SDG 14 of the 2030 Agenda for Sustainable Development and the Sustainable Development Goals calls on governments to 'conserve and sustainably use the oceans, seas and marine resources for sustainable development.' Key targets focus on combating marine pollution, introducing the sustainable management of fisheries, aquaculture and tourism, supporting small-scale artisanal fisheries, protecting marine and coastal ecosystems, fisheries regulations, and addressing climate change impacts.

Local initiatives include:

- Belize introduced no-take zones and marine reserves for sharks.
- The Bahamas created a national shark sanctuary, established closed and open seasons for select grouper and made fishing and harvesting sea turtles illegal.
- Sint Maarten embarked on a major educational campaign to increase awareness and eliminate the incidence of poaching sea turtle nests (Caribbean Loop News, 2022).

- Jamaica created Conch Clusters as part of the private sector Complete Caribbean project to move towards a competitive and sustainable queen conch market.
- However, during the pandemic, Grenada's lack of available volunteers to monitor beaches, delayed government permits, and reduced site monitoring due to movement restrictions resulted in increased poaching activities (Working Abroad Projects, 2020).
- Countries are establishing more Marine Protected Areas (MPAs), national parks, and marine reserves, offering varying levels of protection and human interaction.
- Sensor technologies are being deployed. The Bahamas and Barbados have tagged targeted species to learn more about their migratory patterns and habitat use. Marine monitoring buoys have been deployed to monitor pollution levels in Trinidad and Tobago.

Limiting factors include:

- Outdated legal frameworks to regulate the use of coastal and marine habitats.
- Governments lack the data needed to capture the value of marine resources.
- The fisheries sector is mainly managed by small government departments that remain underfunded and challenged.
- Inadequacies in data collection have often led to disconnected decision-making across governments, resulting in poor practices that cannot be reversed and require expensive mitigation activities.
- Governments often grant approvals to wealthy investors with little regard for long-term environmental impacts and the influence on local communities.
- Aggressive IUU fishing.
- Land and sea pollution.

One possible solution is to develop Marine Protected Areas in conjunction with aquaculture, including e.g. coral reef farming. Madagascar has farmed sea cucumber and seaweed (Raphaëla, et al., 2017). Bonaire, which was the first Caribbean Island to have 100 percent of its surrounding marine environment designated a marine park, has seen this as an opportunity, and has planted more than 40,000 new corals from its in-water coral tree gardens since 2012 (Read, 2022).

4. The importance of planning

The USA's current $1 trillion infrastructure bill includes $47 billion designated for climate resilience. The Federal Emergency Management Agency's program to protect homes at risk from floods is expected to triple to $700 million, and the Army Corps of Engineers construction budget will quadruple, with $11.6 billion for flood control and river dredging. Global investment in urban climate change adaptation increased from $22 billion in 2015–2016 to $30 billion in 2017–2018, but UNEP has estimated that developing countries will have to commit from $140 to $300 billion per year by 2030. In some cases, these costs will become intolerable, and cities will have to implement a combination of sea defences and managed retreat from the coast.

The New Zealand Model

About 13 percent of the population of New Zealand (675,000 people) live in areas that will be increasingly prone to flooding, with another 1.5 percent (72,065) in areas that will be affected by extreme sea level rise. Between 2007 and 2017, floods and droughts cost about $840m in insured damages and economic losses, but this is likely to increase as a result of climate change. The residential building stock at risk is currently valued at some $100bn (McClure, 2022).

New Zealand has therefore developed a set of proposals for changes to planning regulations to stop further building of public housing in hazardous areas, create incentives for development away from high-risk areas, require the disclosure of information about climate risks to buyers and builders, update the building code to incorporate the need to survive higher sea levels, storms and floods, and designate sites with high cultural values for protection. The changes will be phased in over six years. However, the government's proposed changes have met resistance from people who may see the value of their homes fall sharply if they are in high-risk areas, and who may not be able to obtain building insurance.

New York City

New York City had one of the most comprehensive and advanced resiliency plans in the USA, but Hurricane Sandy in 2009 resulted in a 14-foot storm surge that flooded 17 percent of the city (51 square miles), an area 150 percent larger than federal flood maps predicted was possible. In 2013 the city therefore published an even more comprehensive plan to prepare for future hurricanes. This plan guided over $20 billion in subsequent investments, including back-up generators (on roofs) and relocated boilers, porous pavement that can absorb water during floods, white roofs to deflect heat, roof gardens to absorb rainwater, community rooms that can serve as shelters, elevated building entrances to prevent water penetration, portable flood barriers and over 70 'blue belts,', a system that connects storm drains to streams, ponds, rain gardens and retention basins to store and slowly release surges of water. The city is also planning to build a system of flood barriers, berms, floodgates and stone walls to protect Manhattan, at a cost of 1.45 billion, and considering building a 6-mile chain of artificial islands with retractable gates along the city's outer harbour; the latter component alone would cost $119 billion and take about 25 years to build, so smaller, softer and cheaper options are also being considered, such as semi-natural flood barriers (partially submerged breakwaters used as a basis for oyster reefs). In spite of this, construction is still being allowed in high-risk areas, such as the banks of the East River (which is expected to rise by 2.5 feet by 2050 and by 6 feet by 2100).

New Orleans, Miami, Ho Chi Minh City and Rotterdam

In New Orleans, the Army Corps has already spent $14 billion to upgrade levees, and Miami may have to spend even larger sums on pumping systems to mitigate the effects of street flooding. Vietnam is building a 60-kilometer dyke around Ho Chi Minh City with pumping stations and sluice gates. The city of Rotterdam has a large-scale hybrid system that includes sand dunes on the coast, dykes along rivers, floating buildings in areas that cannot be protected and a storm surge barrier with flood-gates to close the river leading into the port.

New approaches to urban planning and development

Cities will have to both mitigate and adapt to climate change. They are the largest sources of greenhouse gas emissions and have the largest concentrations of people vulnerable to the impacts and risks of a changing climate (Frantzeskaki, et al., 2019). As noted earlier, many of the changes needed could be subsumed into a single policy goal of increasing resilience, which has the advantage of aiming to reduce vulnerability to all major hazards rather than just one.

A resilient city can be defined as one that can withstand major stressors by planning and preparing, mitigating where possible and acting swiftly and effectively when necessary to protect the vulnerable and contain and reduce the damage caused by major adverse events (WBG, 2020). This might include, for example, measures to prevent any further settlement in flood-prone areas, constructing sea defences, hardening vital buildings and infrastructure, preparing evacuation plans and building shelters.

Cities are dynamic systems with distinct climatic impacts, so adaptation must be site-specific (WBG, 2020). Cities in low-elevation coastal zones, for example, are threatened by both sea-level rise and storm surges. (WBG, 2020). Improving urban resilience can therefore entail a wide combination of measures, including poverty reduction (WBG, 2020), as poverty and the fear of looting is one of the most salient reasons why people may be reluctant to comply when told to evacuate an area.

Learning-focused interventions such as policy experiments and social networks that promote knowledge exchange can also play an important role in urban social climate change adaptation (Egerer, et al., 2021), as this allows cities to develop more local solutions to mitigate the impacts of climate change (Frantzeskaki, et al., 2019). Building urban resilience necessitates not only good decision-making by those in positions of authority, but also a strong network of institutions and social networks that can engage in the process (WBG, 2020). This involves integrating both technical assessments and community-based participatory approaches. Academies of Sciences and local universities can play a key role in this regard by helping cities to integrate scientific knowledge and community viewpoints and priorities (WBG, 2020).

Many cities in the Caribbean already have a complex combination of challenges, including informal settlements, crime, poverty, inadequate infrastructure and environmental deterioration (WBG, 2020). Urban resilience initiatives therefore have to play multiple roles such as, for example, climate change mitigation and local economic development. For example, city initiatives to strengthen the durability and reliability of urban transport infrastructure can also make the city more attractive to investors (WBG, 2020).

Policy integration is the key to successful urban resilience strategies. For example:

- Rapid urbanization, the rise of informal settlements, poverty, poor infrastructure, and environmental deterioration are all challenges for many cities. Many of the same factors increase vulnerability to climate change, so an *integrated policy approach* is required. There is also a significant overlap between hazard reduction and climate adaptation measures, so these too can be combined in many cases (except that it is important to allow for more gradual climate changes as well as rapid onset disasters).
- Many sectors will be affected by climate change, including land use, housing, transportation, public health, water supply and sanitation, solid waste, food security, and energy, so *cross-sector collaboration* is vital. Cities can also engage local communities and encourage contributions to policy in order to improve understanding of the specific local implications of climate change.
- *Policy integration* is also the key to both reducing the cost of change and using the reforms to create attractive new investment opportunities. This also allows co-financing, linking diverse funding sources (including e.g. municipal revenue, national government funds, external grant funds, concessional financing or market-based approaches to promote efficiency and private sector participation (WBG, 2020)) to give better returns.
- Almost all of these initiatives require the better collection and management of data, so most of the cities with urban resilience strategies are also becoming *smart cities*, integrating communications infrastructure into all aspects of life (NEC, 2022). The smart city concept can be used as the ICT backbone to support all of the other policy initiatives.

All of the concepts described above have to be integrated into urban design and planning processes. Urban design is the process of conceptualising and shaping the physical setting, the

types of buildings and the utilization and organization of the spaces between them, involving many design processes (UDG, 2020). Rapid advances in communication, energy and transport technologies have created new options for urban design, and some contemporary models now consider cities as complex systems with biological, social, and technological components that interact with one another and with the external environment (Fink, et al., 2011). The range of urban design approaches can be seen in the schematic below.

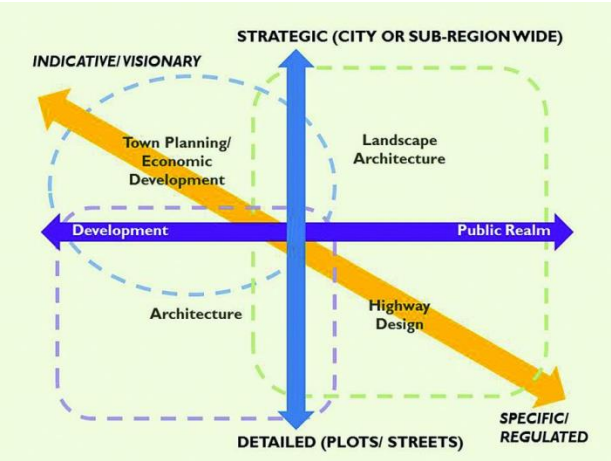


Figure 14: Roger Evans, 'Shaping Towns' presentation, Bristol, 2012

Some other examples of the conceptualization of urban design:

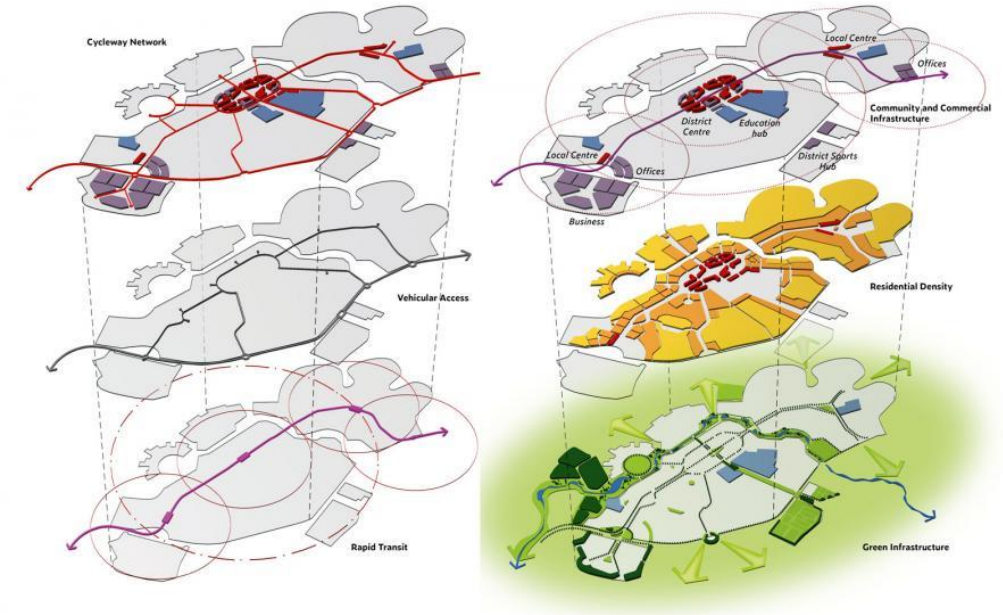


Figure 15: David Lock Associates, Milton Keynes 2050 (UDG, 2020)

Urban planning is the act of developing the structures of a city, including its policies, infrastructure, neighbourhoods, building codes, and regulations (Terracast, 2019). Urban planning and regulation is vital to ensure that water, energy and transport infrastructure keeps abreast of urban growth and that buildings do not get built on unstable slopes or in areas liable to flooding, although the process is in some cases vitiated by weak or corrupt governance. A more universal challenge is that urban planning is a complex process that relies on a variety of interconnected factors, including politics, mapping, building control, regulatory and legal procedures, funding and environmental management (Johnson & Caroca Fernandez, 2020), which means that visions are rarely fully realized.

Throughout history, the powerful economic and social forces of the day have shaped the city. The industrialisation of the economy dramatically altered the configuration of towns, transforming them into workshops. Now the service sector is reshaping cities into a locus of exchange for ideas, goods and services to be traded in face-to-face or mediated markets backed and networked by new technologies. Urban design contributes to the challenge of adapting the city to this structural transformation by establishing new spatial structures and reshaping the urban fabric (Madanipour, 2006).

Most Caribbean nations have still done relatively little to incorporate resilience or disaster mitigation into urban design parameters (Johnson & Caroca Fernandez, 2020). This is for a number of reasons, including weak governance and corruption in some cases, the unplanned spread of informal settlements, the inadequate provision of basic infrastructure and services, air and water pollution, high rates of crime and violence, unemployment, urban poverty and an extensive informal sector. These weaknesses have national consequences, as some two-thirds of the Caribbean population is urban (Klaufus & Jaffe, 2015), and therefore concentrated in some of the most exposed areas.

Most of the Caribbean nations also have high levels of inequality, which is represented in urban structures. There are high levels of violence in a number of Caribbean cities, notably in Jamaica and Haiti, largely concentrated in the poorest communities (Klaufus & Jaffe, 2015). The wealthy

therefore tend to live in exclusive gated communities with security guards; these walls reinforce class divides, exacerbating physical and social segregation and alienation (Irazábal, 2009). The violence in poor communities reduces social capital and the quality of life, and the disparity between rich and poor entrenches urban forms that favour social and physical isolation (Irazábal, 2009).

The Caribbean therefore needs to reinvent and reinvigorate urban planning in order to escape from these deeply dysfunctional problems. This will require both proactive planning for a more sustainable and equitable future, and retrofitting current settlements through public capital investments, public-private partnerships, community empowerment, land use controls, and other policy-based planning interventions. Some level of citizen participation is important to ensure public acceptance of the outcomes (and the inescapable trade-offs), which will be hard in a region where the majority of the electorate are so disaffected that they no longer vote, so countries will have to find innovative ways to reach out to the public in order to generate credible and long-term plans.

There is also a need for context. Each city has a core set of economic functions, its own environmental profile and a unique social, political and cultural history, and these have to be reflected in the policy planning process (Irazábal, 2009).

Climate policies in Latin America and the Caribbean

The Paris Agreement recognizes similar but distinct national obligations, and employs the Nationally Determined Contribution (NDC) framework and a voluntary approach to develop state pledges. Latin America and Caribbean was an early adopter of the NDC framework. This resulted in some ambitious decarbonization plans, in particular in the energy and transportation sectors. With regard to execution, however, the difficulty remains the same: converting ambitious goals into achievable and measurable outcomes. This requires that finance and planning ministries work together with environmental ministries to enable comprehensive climate policy mainstreaming and deliver Paris-aligned budgets and project pipelines (Cárdenas, Bonilla, & Brusa, 2021), but inter-ministry coordination is relatively rare in the region. Another part of the challenge is that policies have to be implemented against a background of limited

resources and relatively high levels of poverty and inequality (Cárdenas, Bonilla, & Brusa, 2021).

However, the Barbados government's Roofs to Reefs Program (R2RP) provides a good example of a whole-of-government initiative that blends climate mitigation and adaptation considerations with social policy and infrastructural resilience to natural disasters such as hurricanes. The R2RP, which has received strong support from the Ministry of Economic Affairs and Investment, aims to improve the resilience of the housing stock as well as access to water and sanitation, while eliminating pit toilets and promoting the use of solar and other green energy options to reduce reliance on fossil fuels. It also aims to address direct power transfer, improve water quality, and reduce waste quantities and impacts (both solid and liquid). These efforts are intended to result in improved living conditions and terrestrial ecosystems (Cárdenas, Bonilla, & Brusa, 2021)**.** In essence, as summed up by UNDESA, "rapid and unplanned urban growth threatens sustainable development when the necessary infrastructure is not developed or when policies are not implemented to ensure that the benefits of city life are equitably shared." (Schultz, 2014)**.**

Integrated climate change strategies in the Caribbean

Some of the key measures that Caribbean nations could take include the following:

1. To avoid fragmentation in public policy formulation and decision-making, water sector planning should be integrated with other sectors such as land use, housing, energy, transport and economic development. IUWM assessments can also include determining the quantity and quality of a water resource, estimating present and future demands, and anticipating the consequences of climate change. This approach can greatly improve the reliability of supply and reduce the number of people who lack adequate water and sanitation (Bahri, 2012).
2. Coral reefs, mangroves, seagrass and tidal saltmarshes play a role in sequestering carbon, and coral reefs and mangroves are coastal defence assets, breaking storm wave action, stabilizing sediment, minimizing erosion, and thereby mitigating some of the effects of sea-level rise. Minimizing destruction of these habitats and expanding national protection zones will support the protection and conservation of marine habitats and maintain

natural defences against disasters. Low-cost solutions include enacting and updating existing legislation to increase ecosystem protection from development in sensitive areas, regulate other forms of unsustainable use, increase public education measures and research programs to monitor habitat characteristics.

3. Tourism is economically vital, but much tourism development has been environmentally destructive. Tourist activities have contributed to the destruction of corals from diving gear and boats, sedimentation, sewage, sunscreen and plastic waste. The industry could be reoriented towards ecotourism tours in protected areas and managed marine parks, with hotels zoned out of protected areas on the coast. A 2019 study by the Nature Conservancy found that many tourism activities depend on coral reefs, including beach activities, recreational fishing, swimming and boating excursions (The Nature Conservancy, 2018), and that coral reefs therefore support 36 billion dollars (2017) in tourism revenue (The Nature Conservancy, 2017).
4. The proximity of essential infrastructure such as roadways, hospitals and public buildings to the coast makes them susceptible to coastal flooding and destruction. The cost of sea defences is often too expensive for Governments throughout the region; but strengthening planning codes to expand no-build zones along the coast and revising building codes for residential and commercial buildings will mitigate the environmental and financial pressures of climate change.

Integrated policy options

Caribbean nations face diverse threats, and will have to implement a range of adaptive strategies. Give limited economic resources, it is important to identify **integrated policy options** that can reduce multiple risks or solve a number of problems at the same time. At present, most government departments do not coordinate their policies, resulting in policy conflicts and a dearth of useful synergies.

Global issues such as climate change present a particular challenge to human decision-making processes. The impacts are extensive, and some of them cannot be solved if they are treated separately. For example, if a country were to try to reduce its dependency on imported hydrocarbons by encouraging local farmers to move into ethanol production; that might offset

demand for oil but increase food prices, followed by a loss of biodiversity as agriculture expanded into unconverted land. In such cases, it is important to try to solve more than one problem at the same time so that impacts are actually reduced rather than displaced into other sectors.

This requires a systems approach, which involves identifying these connections and then looking for the optimal multi-dimensional solution. One option might be to develop a synthetic biofuel, for example, that did not compete directly with the production of food and the maintenance of biodiversity, another option might be to amend building codes to encourage the development of buildings with net zero energy demand to reduce fuel consumption. In this case, the second option of reducing consumption would be preferable, as it could be used to achieve multiple outcomes; reduced dependence on imported energy, higher levels of disposable income, reduced environmental impact and greater resilience to disasters.

Most policy development is currently done within individual Ministries, which means that plans do not always take sufficient account of potential consequences that fall within the jurisdiction of other Ministries. Inter-Ministry committees are generally used to try to coordinate approaches, but this cannot substitute for a lack of coherence in the actual policies. The integration of social, economic and environmental information into a single decision support process significantly reduces the chance of policy conflicts, and thereby improves the cost-effectiveness of government operations.

Better planning, building resilience

Over time, zoning could move urban concentrations and infrastructure into safer areas, and stronger building codes could reduce the number of casualties. However, this is likely to take many years, so it is also important to develop interim measures to reduce the cost of a major storm.

Defensive measures for Caribbean cities can start far outside the urban areas, and include more resilient power systems, dispersed water capture and storage, and storm water management, hardened flood defences for transport infrastructure, including berms and other forms of active

beach management, and measures to protect surrounding reefs and mangroves. Key steps inside the urban areas would include relocating some government buildings and hospitals, protecting schools, police and military bases, building shelters and storing supplies, using permeable road paving to absorb flash floods, specifying net-zero buildings to reduce energy demand and changing building control regulation to ensure that all new-build is designed to withstand severe storms. Cities can also be reconfigured to supply some of their own food and water with rainwater harvesting, vertical forests (where buildings are designed to support dense vegetation) and urban agriculture.

This would require a high level of policy integration (e.g. energy security, climate change adaptation and disaster preparedness) and policy coherence (energy, water, agriculture, urban planning guidelines and building controls), but could then solve multiple problems. For example, the post-disaster relief efforts in most countries are seriously handicapped by the lack of electricity in the critical disaster and post-disaster periods and the consequent inability to operate lighting, air conditioning and refrigeration, water pumps and communication systems. This problem arises directly from the centralized generation of electricity and the network of distribution systems. These systems, especially the distribution poles and lines, are usually physically damaged during a hurricane or similar disaster, and it takes time to bridge the broken sections. Some sites have standby generators, but the majority of the population remains vulnerable. The development of more energy-efficient and self-sufficient buildings, with decentralized sources of energy such as biogas and photovoltaic supplies, should therefore also be seen as an essential component of disaster preparedness.

In island nations, it is particularly important to integrate the redevelopment of cities with water management, coastal zone management and the sustainable development of the blue economy. With domestic agriculture challenged by climate change, the future of island nations will increasingly depend on the blue economy for transport, energy, fisheries, coastal protection and bio-harvesting, which makes it essential to stop using the sea as the ultimate recipient for sewage, agrochemicals, solvents, oil, plastic and other solid waste that is currently discharged via streams and storm drains.

Jamaica's economy, for example, is heavily dependent on the marine environment. It is the basis for both the cruise industry and beach-based tourism, which comprise Jamaica's largest source of employment and second largest source of foreign exchange; sustains the fishing industry, a significant source of protein in the diet; supports the shipping industry, which transports most of Jamaica's imports and exports; and absorbs a significant part of Jamaica's liquid and solid waste. It is also Jamaica's most significant resource; the exclusive economic zone (EEZ), or maritime territory, is 235,000 km², 21 times larger than the island itself. Jamaica's blue economy resources are largely unmapped, but potentially include off-shore wind farms, sea-bed turbines, oil, gas and mineral assets and biological/genetic resources.

This resource is not currently well-managed. The Caribbean region includes ten of the world's top thirty marine polluters per capita. The reasons include lack of sanitary landfills, weak enforcement, and poor waste management provision with minimal recycling. Pollution includes agricultural and sewage run-off, illegal dumping of waste on land and illegal discharges from cruise ships and freighters, but about one-third of the waste in the Caribbean Sea is single-use plastic (SUP) and polystyrene. The region consumes about 300,000 tons of plastic each year, most of which then becomes a disposal problem. Most food and manufactured goods are imported, along with a substantial amount of plastic in the form of packaging used to protect imported food and other products.

Disposable plastic became ubiquitous in Jamaica in parallel with the adoption of a more consumerist lifestyle and convenience-food based diet. Until recently, stores gave free plastic bags to their customers, and take-out meals came with polystyrene containers, plastic bottles, plastic straws and cutlery, all placed in another plastic bag for convenient carrying. Most of these disposable items were not recovered. Only half of the region's solid waste is disposed of in sanitary landfills. Jamaica does rather better, some 75 percent of solid waste is collected, but most of the remainder is burnt, littered or goes into storm drains and ultimately ends up in the ocean. The plastic waste that does reach authorized landfills is comingled with all other forms of domestic waste, which increases the complexity and cost of any recovery option.

Urban resource and waste management systems, supplemented by changing lifestyles and the development of alternative products, are therefore vital to protecting the blue economy and hence the future of the country.

Water management

Improved water management is one of the most important components of any strategy for adapting to climate change. Climate change will cause droughts in some areas, floods in others, and both will require much more efficient methods for storing, cleaning, buffering, recovering, reusing and disposing of water. In Jamaica, for example, drinking water, waste water and storm water are managed separately. Potable water is pumped uphill to many consumers in Jamaica and then used to flush lavatories and water gardens, and the waste water then contaminates the water table with sewage. The management of storm-water is equally problematic. Most Caribbean cities have covered large areas with paved and impermeable surfaces so that rain is no longer absorbed but channelled into drains, but roads are often flooded when there is heavy rain because drainage is inadequate.

Some cities are now implementing a new strategy of integrating the management of water across domestic and industrial use, urban agriculture, environment, biodiversity and air quality management. Chicago, one of the cities taking a new approach to water management, has been building ‘green alleys’ since 2006. These are streets with permeable paving that allow rain to soak into layers of sand and porous rock that filter and decontaminate the water before it reaches the ground water table. This not only helps to prevent flooding, it recharges the aquifers from which the city can then draw water. Other cities are now using parks and restored wetlands, vegetated rooftops, roadside plantings and gardens to absorb excess rainwater and eliminate flooding, while also reducing runoff. The parks and gardens used to control storm water also reduce particulate matter in the air, which in turn reduces the incidence of asthma, bronchitis and heart failure. Demand for fresh water in some cities is now in part met with rainwater harvesting, grey water (from basins and showers) is used to flush toilets, and sewage is filtered through reed beds, so that the cleaned water can then filter down into the water table. With a combination of strategies like this, cities can reduce the amount and cost of the water that they consume, prevent pollution and flooding, and breathe cleaner air.

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