Goldman Sachs

GLOBAL MARKETS INSTITUTE

September 2019

TAKING THE HEAT

Making cities resilient to climate change

Amanda Hindlian
amanda.hindlian@gs.com

Sandra Lawson
sandra.lawson@gs.com

Sonya Banerjee
sonya.banerjee@gs.com

Dan Duggan, Ph.D.
dan.duggan@gs.com

Michael Hinds
michael.hinds@gs.com

The Goldman Sachs Group, Inc.

Table of Contents

The Global Markets Institute is the research think tank within Goldman Sachs Global Investment Research. For other important disclosures, see the Disclosure Appendix.

The authors would like to thank Ingrid Tierens, Yi Wang, Jennifer Carey, Nicola Doll, Patricia Pacheco, Raunak Chitlangia and Biddu Singh.

Executive summary

- **Although the timing, scope and magnitude of the consequences of global warming remain uncertain, the potential risks are significant.** Attention has focused on the need to reduce greenhouse gas emissions, and far more work will be needed here. Even as this work progresses, however, there will also be a need for *adaptation* efforts that can help the world withstand the potential effects of climate change.
- **Climate change could reshape the earth.** Negative outcomes that could make adaptation critical in coming years include higher temperatures, more intense storms, melting glaciers, rising sea levels, shifting agricultural patterns, pressure on food and water and new threats to human health.
- **Cities will be on the frontlines of climate adaptation.** Although the need for adaptation is likely to be widespread, we focus here on cities. Because they are home to more than half the world's population and generate roughly eighty percent of global GDP, cities will find themselves at the epicenter of this challenge. Rapid urbanization in some developing countries will also likely sharpen the focus on cities.
- **Urban adaptation could drive one of the largest infrastructure build-outs in history.** Greater resilience will likely require extensive urban planning, with investments in coastal protections, climate-resilient construction, more robust infrastructure, upgraded water and waste-management systems, energy resilience and stronger communications and transportation systems. Despite the uncertainty around the timing and scale of the impact, it may be prudent for some cities to start investing in adaptation now and to do so in ways that allow for maximum flexibility in the future – without committing to any one specific climate projection.
- **Given the scale of the task, urban adaptation will likely need to draw on innovative sources of financing.** Even the most economically prosperous cities will likely need to look beyond tax revenues to other sources of funding, including central-government funds, public-private partnerships, institutional investors, insurance and, in developing economies, international financial institutions. "Soft" infrastructure, such as laws, regulations and markets that support financing, will matter too.
- **Adaptation may raise questions of fairness.** Urban adaptation may raise questions of fairness – such as which cities can support adaptation and which cannot, or where limited resources should be directed within cities. This is likely to be true even in the most prosperous cities; the fact that many of the problems could prove to be local and specific could exacerbate this dynamic.

1. Introduction: Making cities resilient to climate change

There are many ways to look at climate change – scientific, technological, economic, political, social and more. In this paper, we discuss the need for greater resilience in the face of a warming world and the steps cities can take to adapt to climate change.

We start with the broadly accepted scientific consensus that human activity – principally the emission of greenhouse gases – is causing the earth to warm in ways that are affecting the climate. To be sure, political debates persist about the extent of climate change, as well as the desirability and efficacy of ways to counter it. But climate scientists generally agree that the risks of significant negative consequences from continued warming are high – even if there isn't broad agreement or clarity as to the exact timing, scope or magnitude of these risks.

Potential risks include higher mean surface and ocean temperatures, more frequent and more intense weather events, melting glaciers, rising sea levels, shifting agricultural patterns, pressure on food and drinking water, new threats to human health and harm to many natural ecosystems.

Some evidence suggests that these trends are already underway – in fact, our own review of global temperature data over the last 60 years supports the view that the earth has already warmed. And if the scientific consensus is correct, the negative consequences of a warming world may well play out over several decades to come, even if efforts to limit greenhouse gas emissions are successful today. This is because the ongoing impact of past emissions is expected to sustain warming well into the future.

The path ahead isn't clear, and tomorrow's reality may not match today's expectations – it may be better, or worse, or it may play out in unimagined ways. If climate change is worse than anticipated, even adaptive measures that seem prudent today may prove to be insufficient in the future. Or, if technological innovation and changing human behavior can reduce emissions and warming in the years ahead, climate outcomes might actually be better than what scientists generally anticipate today.

All of this makes planning for the future highly challenging and raises important questions about *when* countries, cities, companies and investors should start to adapt to the potential effects of climate change. There isn't a clear answer to this question. An investment approach might suggest that it makes sense to "wait and see," allowing time for new information to emerge before making any major investments. But the most significant effects of climate change are likely to be "tail events," which are inherently unpredictable in both their timing and their severity.

Waiting won't necessarily generate more information about these idiosyncratic events. Waiting may instead mean running out of time to prevent severe damages, especially if the pace of climate change accelerates. It may therefore make sense to start investing now – but to build in ways that allow for maximum flexibility and that leave room for innovation and economies of scale to reduce the costs of climate defense over time.

With this in mind, we hone in on the implications for cities. We do so because the combination of their economic activity and population densities is likely to put them on the frontlines of adaptation to climate change. Cities generate roughly 80% of global GDP and are home to more than half of the world's population today, a share that the United Nations projects will reach two-thirds by 2050.

Many urban areas are already focusing on reducing greenhouse gas emissions. They are engaging in activities like planting more green spaces, utilizing alternative sources of energy and using data to more efficiently operate roads and railways – what are often called "mitigation" approaches. While some work has been done to make cities more resilient to climate change, far more efforts are needed for cities to withstand the potential effects of a warming world – what are typically referred to as "adaptation" measures.

To that end, there is a wide range of potential urban adaptation investments, some of which may be highly specific to the on-the-ground needs of a particular area. These include coastal protections, climate-resilient construction, more robust infrastructure, upgraded transport systems and more. In fact, urban adaptation could drive one of the largest global infrastructure build-outs in history.

But not all cities are created equal, which may raise questions of fairness. On the one hand, rapidly-urbanizing cities in developing economies will likely need to incorporate climate concerns into the already extensive challenges of building infrastructure for their expanding populations. They may also face challenges in accessing the funding they will need, for reasons including a lack of credit ratings or inadequate tax bases.

On the other hand, densely populated cities in developed economies that are hubs of economic activity are more likely both to have and to attract the economic resources to defend against climate change. They are also more likely to have a financing track record that makes raising capital for urban investments less onerous. But even these more prosperous cities may face questions of equity when deciding how to allocate limited resources. For example, should cities invest to strengthen flood defenses in their business districts, or should they upgrade public housing in flood-prone areas? Many similar choices will arise.

All cities will need to consider the hurdles associated with raising funding to support adaptation efforts. Even thriving cities will likely need to look beyond local tax revenues to central-government funding, public-private partnerships, institutional investors and international financial institutions, especially for projects in developing economies. And in both developed and emerging economies, the insurance sector can play an important role in pricing risk and discouraging moral hazard. "Soft" infrastructure, such as domestic capital markets, municipal creditworthiness, supportive financial regulation, strong tax administration and integrated urban planning, will help to support this extensive infrastructure build-out.

We consider these issues while recognizing both that the path and magnitude of climate change are uncertain – but also that the potential risks could be too great to ignore.

2. Living in a changing climate

The scientific consensus is that the earth has already warmed and is likely to continue to do so for several decades to come. In fact, the data suggest that the earth has already warmed by nearly 1°C compared to the "pre-industrial" period (the commonly used benchmark, defined as the mean temperature from 1850 to 1900).

Our own assessments of the data, seen in Exhibits 1 through 4, show this trend. These exhibits plot the average change in surface temperatures, measured in degrees Celsius from the pre-industrial period, across the globe for each five-year period from 1960 until early 2019. Shades of red reflect warmer temperatures and shades of blue reflect cooler temperatures relative to the pre-industrial period. The black box that appears on the scale to the right of each exhibit captures the range of temperature change experienced regionally over that five-year period. The red arrows on the scale mark the aggregate average temperature change experienced during the same timeframe. Appendix B discusses our methodology.

Two key drivers of continued warming

This trend toward a warmer world appears unlikely to abate in the near or even medium term. There are two key drivers of ongoing global warming. The first is net greenhouse gas emissions, principally of carbon dioxide (CO2). Such emissions would need to be cut dramatically in order to significantly curtail the trajectory of climate change, according to most climate scientists.

For context, the Intergovernmental Panel on Climate Change[1] (IPCC) indicates that limiting cumulative global warming to 1.5°C this century (the goal of the 2015 Paris Agreement) would require global CO2 emissions alone to decline by 45% between 2010 and 2030, and then to reach net zero by 2050. Limiting warming to the still-ambitious goal of 2.0°C this century would require CO2 emissions to decline by 25% between 2010 and 2030, and then to reach net zero by 2070.

Meeting these goals will likely be a challenge. In fact, after a temporary pause in the middle of this decade, global CO2 emissions are again on the rise and reached a new high in 2018.

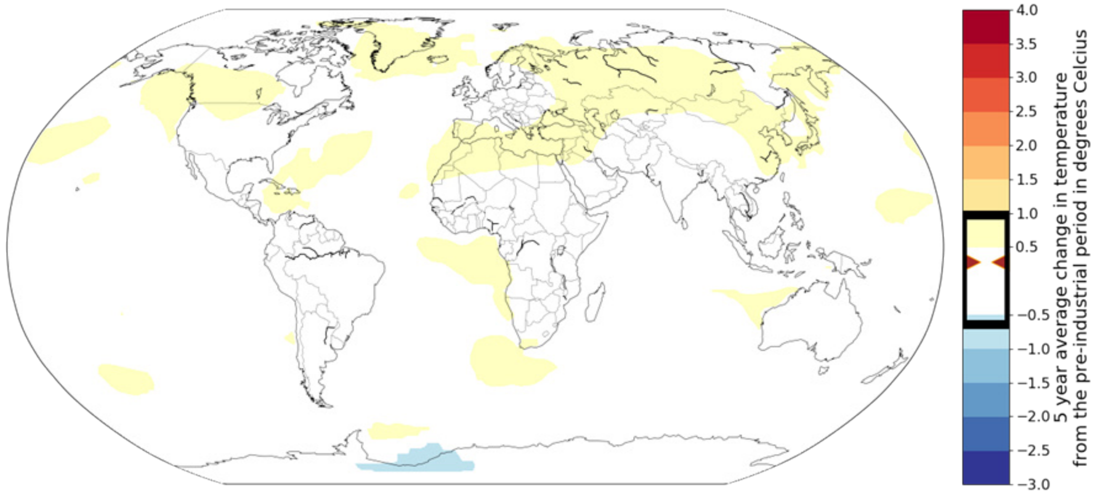
The second reason to expect ongoing climate change is past greenhouse gas emissions. Even if current emissions were actually to reach net zero in the next few years, climate scientists indicate that emissions that are already in the atmosphere are likely to warm the earth for decades to come.

[1] The IPCC was formed in the late 1980s by the United Nations and the World Meteorological Organization. The organization does not conduct its own scientific research but instead coordinates work from scientists around the world to provide regular assessments of the drivers, risks and likely outcomes of climate change, along with the impacts of mitigation and adaptation. The IPCC presents its work using a range of confidence intervals. Other widely-cited reports or experts in the field include the National Climate Assessment in the US, which released its fourth version in late 2018, the Organization for Economic Cooperation and Development (OECD), the International Energy Agency (IEA), China's National Center for Climate Change Strategy and International Cooperation (NCSC) and the US National Oceanic and Atmospheric Administration (NOAA). Other countries, as well as some cities and municipalities, have also issued their own reports, which tend to be more granular in their examination of critical local issues.

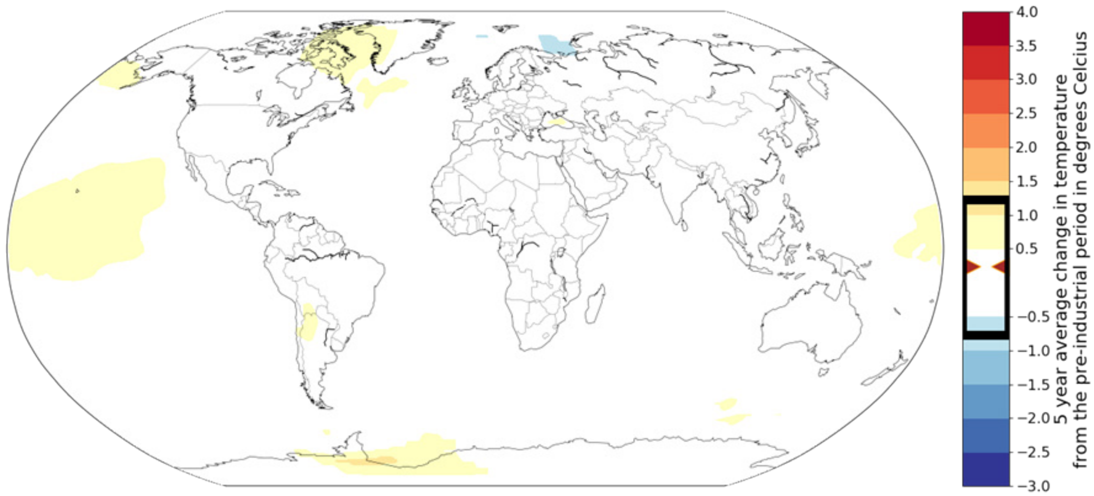
Exhibit 1: Change in global mean surface temperatures, 1960-1974

Average change in temperatures measured against the pre-industrial period

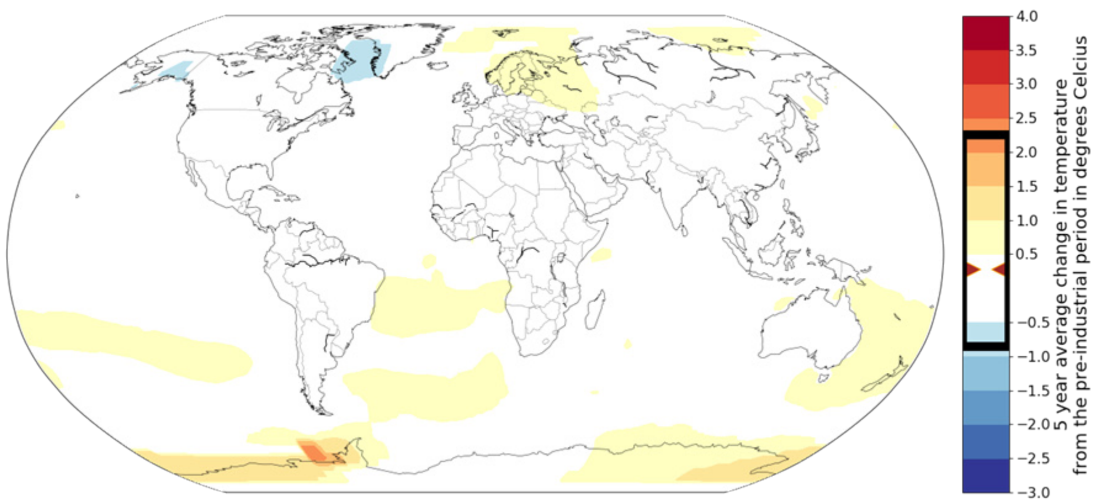
1960-64



1965-69



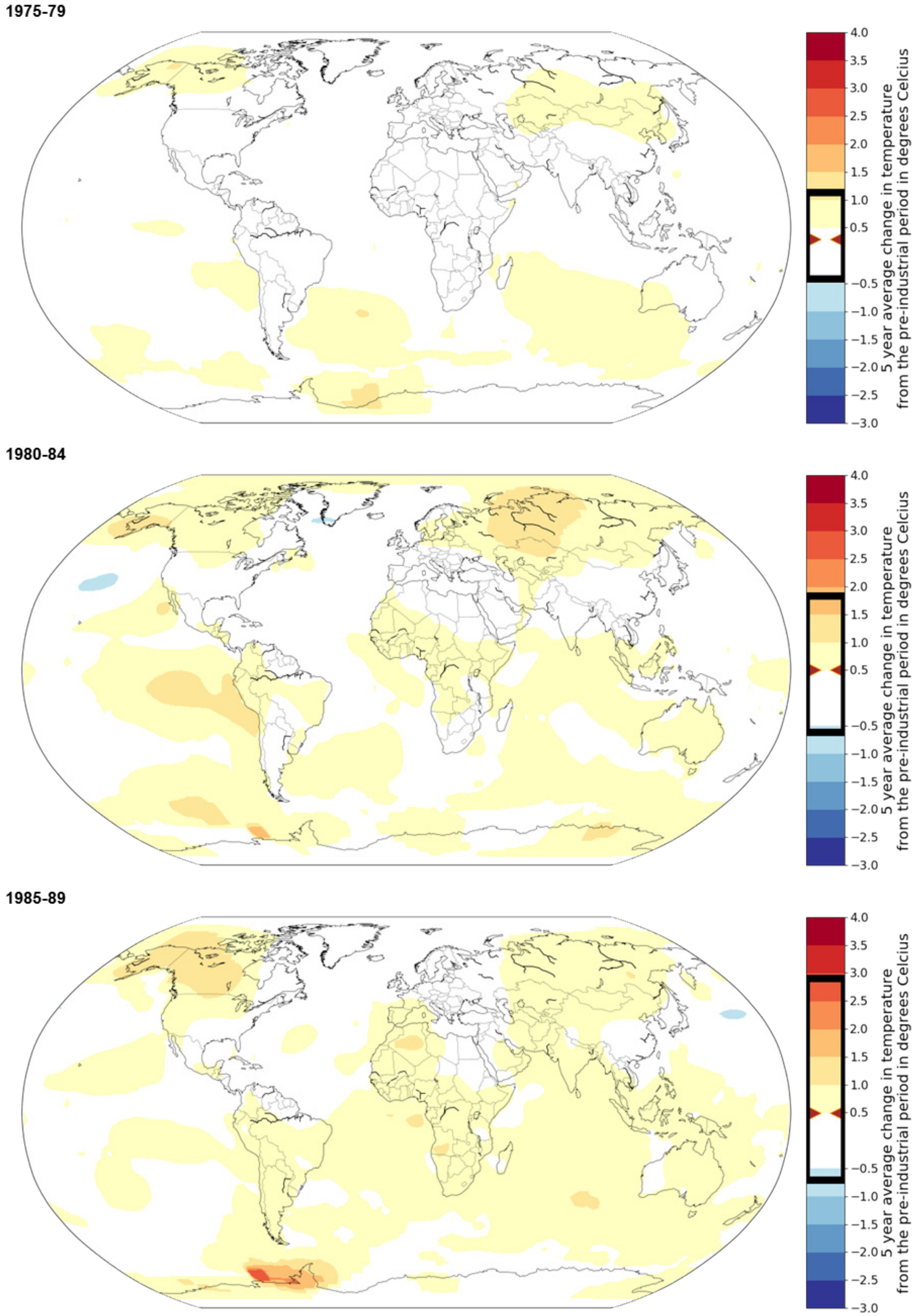
1970-74



Source: NASA's GISTEMP, Goldman Sachs Global Investment Research

Exhibit 2: Change in global mean surface temperatures, 1975-1989

Average change in temperatures measured against the pre-industrial period

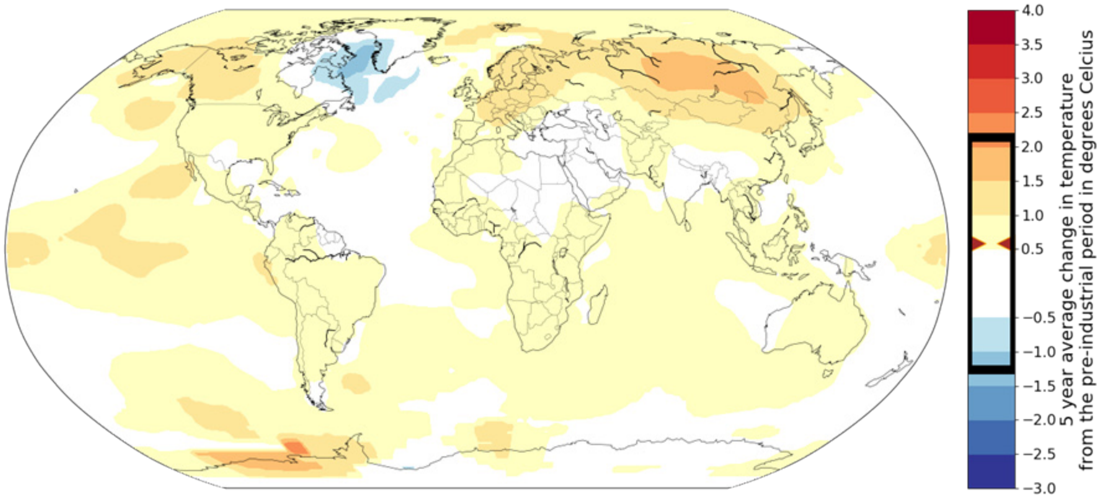


Source: NASA's GISTEMP, Goldman Sachs Global Investment Research

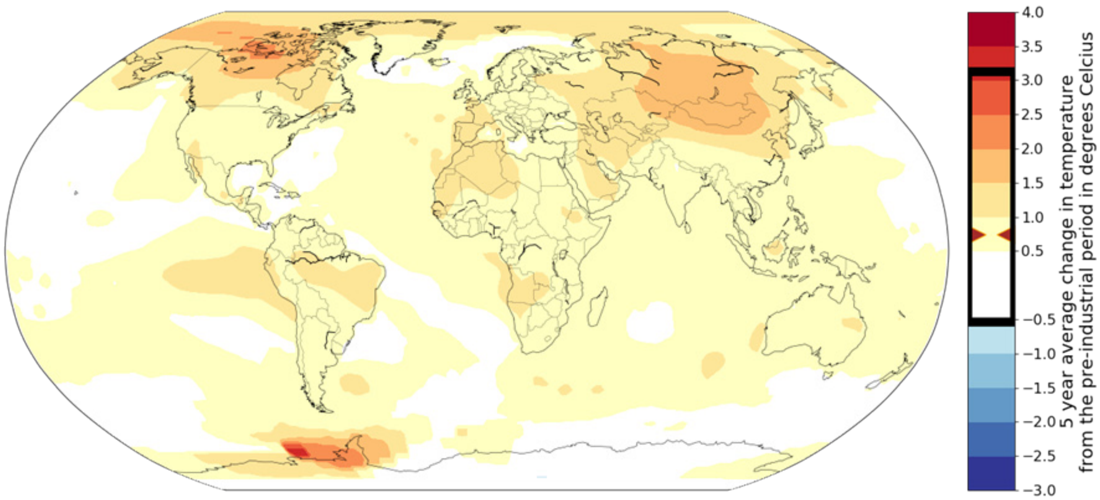
Exhibit 3: Change in global mean surface temperatures, 1990-2004

Average change in temperatures measured against the pre-industrial period

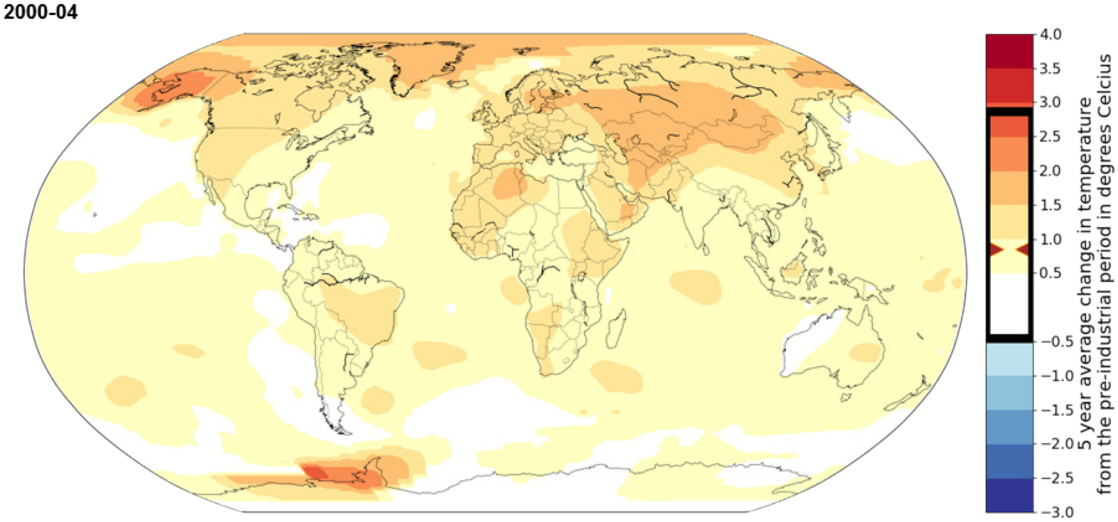
1990-94



1995-99



2000-04

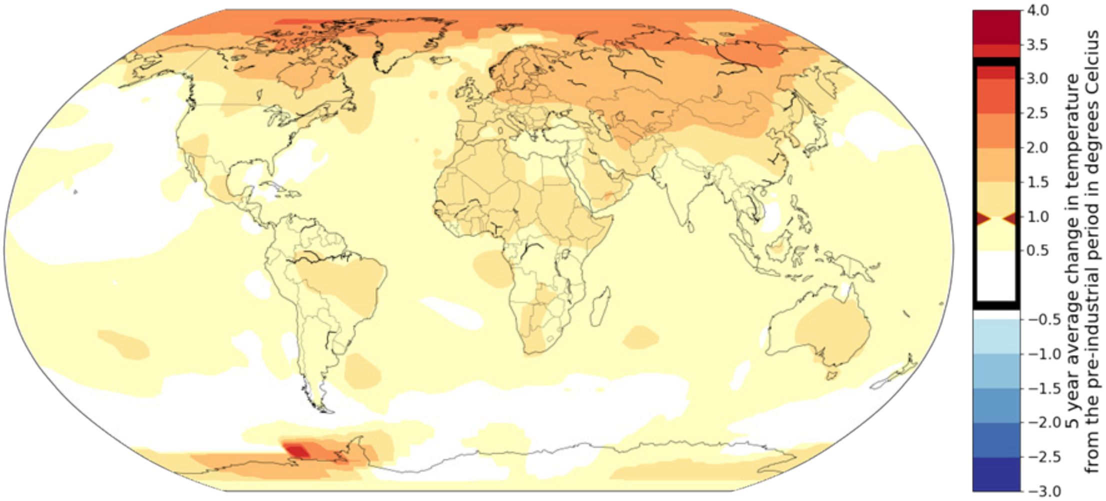


Source: NASA's GISTEMP, Goldman Sachs Global Investment Research

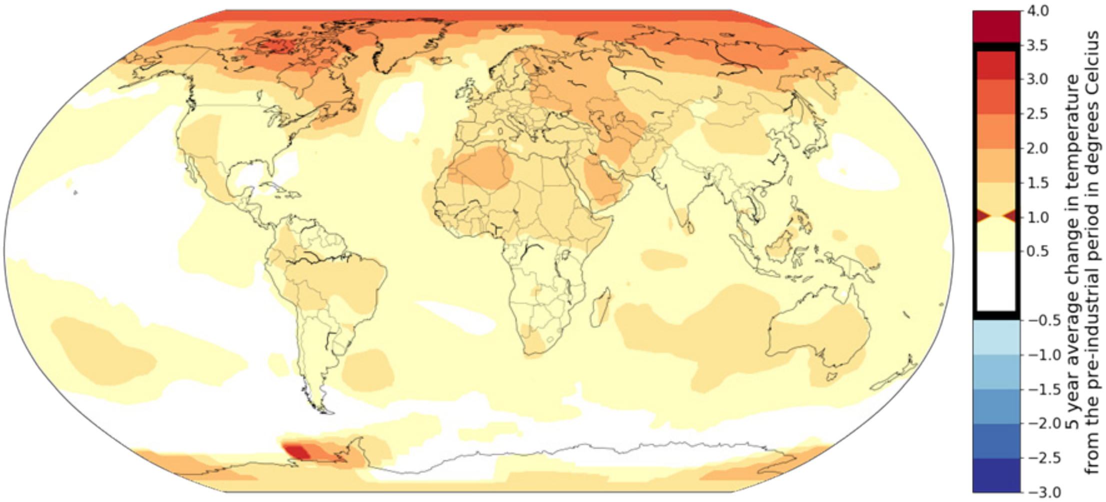
Exhibit 4: Change in global mean surface temperatures, 2005-2019

Average change in temperatures measured against the pre-industrial period

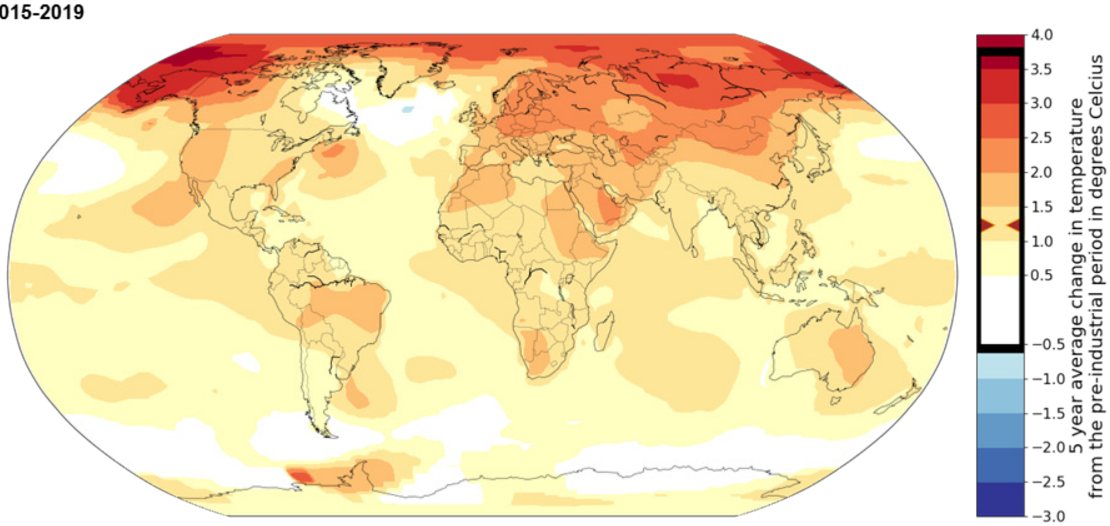
2005-09



2010-2014



2015-2019



Source: NASA's GISTEMP, Goldman Sachs Global Investment Research

Climate projections are uncertain but do not bode well

Although there is broad scientific agreement that climate change is likely to persist, its trajectory, timing and extent are still debated. Many uncertainties contribute to these ongoing debates, among them the differing timeframes of many projections, the potential for idiosyncratic events to unfold, the possibility of unpredictable feedback loops and the assumptions around human behavior that are embedded in climate models. Accordingly, there is little consensus as to exactly how much surface and ocean temperatures may increase and over what timeframe, how high sea levels may rise, how quickly glaciers may (or may not) melt, how ecosystems will react and more.

Recognizing the inherent complexity and uncertainties in climate projections, we don't take a stance on the science or even on the most likely outcomes. Instead we rely principally on the IPCC, which has the broadest global remit and is generally seen as the most comprehensive source of research on climate change.

Appendix A provides more detail on some of the negative consequences of climate change. At the highest level, they could include:

- More frequent, more intense and longer-lasting heatwaves that harm human health, reduce productivity, disrupt economic activity and hurt agriculture.
- More frequent and more destructive weather events, including storms, winds, flooding and fires.
- Changing disease patterns, which could adversely affect human health.
- Shifting agricultural patterns, affecting the availability of food.
- And pressure on the availability and quality of water for drinking and agriculture.

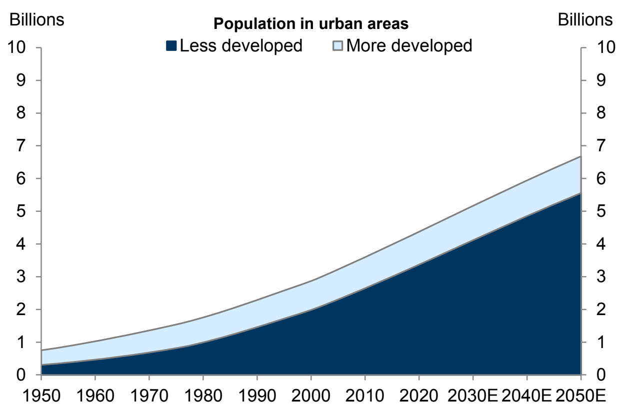
3. Why focus on adaptation in cities?

Although climate change has implications for both urban and rural areas, we focus on cities given their combination of population density and economic activity. Cities are already home to 55% of the world's population (a total of 4.2 billion people), a share that the United Nations projects will rise to 68% by 2050 (to 6.7 billion people, reflecting expected migration patterns and birth and mortality rates). According to the World Economic Forum, cities currently generate roughly 80% of global GDP and consume 75% of the world's natural resources.

There are of course differences between cities in more- and less-developed regions, with 79% of the populations of more-developed regions already residing in cities (roughly 1.0 billion people) versus 51% in less-developed areas (roughly 3.2 billion people). Even so, by 2050, the United Nations expects this gap to narrow in relative terms, with 87% of the population of more-developed regions living in cities versus 66% in less-developed regions. See Exhibits 5 and 6.

Exhibit 5: Most of the world's urban population is in less-developed regions

Number of people in urban areas, 1950-2050E

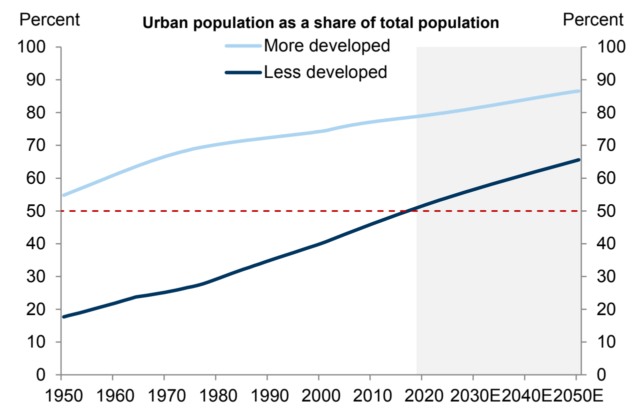


Note: More-developed regions include Europe, Northern America, Australia, New Zealand and Japan. Less-developed regions include Africa, Asia (excluding Japan), Latin America and the Caribbean plus Melanesia, Micronesia and Polynesia.

Source: United Nations, Goldman Sachs Global Investment Research

Exhibit 6: While the share of people in cities is higher in more-developed regions, less-developed countries are narrowing the gap

Share of population in urban areas, 1950-2050E



Note: More-developed regions include Europe, Northern America, Australia, New Zealand and Japan. Less-developed regions include Africa, Asia (excluding Japan), Latin America and the Caribbean plus Melanesia, Micronesia and Polynesia.

Source: United Nations, Goldman Sachs Global Investment Research

Cities are vulnerable to climate change on several fronts. Risks come from higher temperatures, more frequent and/or intense storms, rising sea levels and stronger storm surges, all of which can affect economic activity, damage infrastructure – from buildings to transportation to water and waste-management systems – and disproportionately harm vulnerable residents.

But not all cities are created equal. Some urban areas have inherent advantages that should help them adjust to the impact of a warming climate. Chief among these are a high population density and a concentration of economic activity. The benefits of protecting these cities can be distributed and enjoyed over a large population, and major cities tend to have the local tax bases, economic resources and creditworthiness that will likely be needed to draw financing for major projects.

These cities may benefit from their ability to use zoning, environmental regulations and integrated urban-planning capabilities to address the effects of climate change that harm human health and well-being, among them pollution, "heat-island" effects and flooding. For example, zoning regulations can be developed (or changed) to allow for greater population density, which can reduce travel and thus pollution and carbon emissions (and yield other non-climate benefits as well).

Case study: using urban planning to take a medium-term perspective in Copenhagen

- In 2011 Copenhagen issued a report outlining the short- and medium-term challenges of climate change for the city.
- While recognizing the uncertainty around the long-term outlook, the city decided that "it nevertheless makes good sense to start on climate adaptation now" – in part to "avoid making the wrong decisions."
- The plan recommended focusing on integrating and "climate-proofing" municipal planning. It also called for the city to consider adaptation in the context not just of climate change but also of supporting economic growth and improving residents' quality of life. For example, developing green spaces could reduce heating costs and emissions, manage storm-water and at the same time increase recreational opportunities.
- The city's focus is on prevention and rapid clean-up. In the specific case of flooding, for example, adaptive actions would include:
  - First, *reducing the likelihood* by building dikes, building on higher ground and bolstering sewer capacity and storm-water management.
  - Second, if that is insufficient, *reducing the scale* of the harm by establishing early-warning systems, creating storage capacity in public spaces and water-proofing basements.
  - Third, if the second level of protections is insufficient, *reducing vulnerability* by focusing on rapid clean-up.

Even these well-placed cities will likely need to grapple with critical questions of fairness, however. In an era of constrained resources, when the financial requirements of adaptation may well outstrip the financing available, politicians will need to build consensus around prioritizing projects. For example, do the environmental benefits of restricting private cars from the city center outweigh the economic harm caused to people who have few alternative ways of getting to work?

At the same time, other urban areas are likely to face greater challenges. Some cities may ultimately find combating climate change to be prohibitively expensive or technically unfeasible. These are likely to be cities with lower population densities, more limited economic activity and/or disadvantaged geographies (for instance low-lying delta cities) – essentially cities that combine high costs of adjustment with limited financial resources to pay for it. And some cities in emerging economies in particular may find that, despite high population densities and a concentration of economic activity, the multiple challenges of rapid urbanization prevent them from dedicating the necessary resources to adapt to climate change.

If the climate continues to worsen, or if the pace of change accelerates, the costs may ultimately become too great for these cities relative to the resources that are available to them. And this too can raise significant concerns around equity. In these cases, over both the medium and long term, people and economic activity may move to better-positioned cities where higher population densities and greater economic activity make climate defense more feasible.

This can create a vicious cycle for the "sending" cities: as populations shrink and economic activity declines, financing climate-change defenses may become all the more difficult, accelerating the decline of these more vulnerable areas. And while the "receiving" cities could stand to benefit from greater economic activity, inward migration brings its own political, economic and social challenges.

Case study: sustainable urban planning in China

- In 2017 China announced the development of a major project, the Xiong'an New Area, designed to relocate people and some non-governmental functions away from Beijing. The project builds on the ground-up development of Shenzhen in the 1980s and Shanghai Pudong in the 1990s and is designed in part to create a model for the growth of other inland cities.
- Key features include planning for a city that is 70% "green and blue," with a park system that brings "forest around the city, wetland into the city" and an expansion of forest coverage to 40% from 11%. The expansion of green space will help to lower the urban heat-island effect, enhance biodiversity and create more opportunities for recreation.
- As part of a nationwide "sponge city" initiative launched in 2013, Xiong'an will also address flooding and water-quality concerns by introducing an expansive reservoir and sewer system to collect, purify and reuse rainfall and waste water. The city also has targets for recycling and environmentally friendly waste treatment.
- The multi-decade master plan also calls for capping population density; creating a low-carbon transportation network; and generating 50% of the city's energy consumption through wind, solar and other renewable technologies.

4. Common challenges in building urban climate resilience

Urban infrastructure will likely be a key area of focus given that much infrastructure is highly vulnerable to the effects of climate change. High temperatures can make road surfaces and rails buckle and can disrupt aviation by making some airports unusable. Winds and storms can cause power outages and destabilize bridges. Flooding can wash away rails and roads, destroy communications systems, overwhelm drainage systems and contaminate drinking water. Forest fires can disrupt economic activity and cause massive economic and personal losses.

The challenges of a warming climate are exacerbated by the fact that existing codes for infrastructure are often designed with reference to historical stresses. To that end, ongoing changes in the climate may make existing building standards dangerously outdated.

What's more, several critical infrastructure sectors operate as networks, with multiple points of connection, including most obviously power, transportation and communications. A network structure has both benefits and drawbacks in terms of defense against climate change. It can be designed, or upgraded, in a way that bolsters resilience by including redundancies and multiple points of connectivity. If one node fails, others should be available.

But the multiple points of connection also can create multiple potential points of failure. The complex nature of network systems creates vulnerabilities in more remote places. This means that defense will need to run end-to-end, against a wide range of conditions. And even strongly redundant webs may still have bottlenecks or pinch points requiring "point defense," such as switching stations or bridges and tunnels into major cities.

A further challenge involves timing. Cities will need to confront the question of *when* to invest in stronger climate resilience. There isn't a clear answer to this question. Because there is so much uncertainty about the long-term outlook – what might happen, where and when – there is a high risk of making the "wrong" choices.

Cities won't want to over-commit to specific climate scenarios. For example, building a seawall to withstand today's "worst-case" 10-foot storm surge won't be of much use if in two decades the surge turns out to be 15 feet. Considering that climate projections have been repeatedly revised to show increasingly severe outcomes, this is a real concern.

Taking an investment approach might suggest that it makes sense instead to "wait and see," allowing time for new information to emerge before making any major investments. While this approach makes sense in many contexts, the case of climate change appears to be different.

The most significant effects of climate change are likely to be the result of "tail events," which are inherently unpredictable in both their timing and their severity. Waiting won't necessarily generate more information about these idiosyncratic events. Waiting may instead mean that cities run out of time to prevent severe damages, especially if the pace of climate change accelerates while they wait.

Therefore it may make sense to start investing now – but to build in ways that allow for maximum flexibility and that leave room for innovation and economies of scale to reduce the costs of climate defense over time. Limited improvements today that can be further strengthened in the future, depending on the actual path of climate change, may prove far more useful than planning for one specific outcome.

What's more, because climate change is a global problem, cities around the world will face common challenges, as we discuss below. Small-scale, local innovation may foster the trial and error that ultimately yields technological breakthroughs and economies of scale that allow adaptation projects to be rolled out more widely.

In the sections that follow we lay out some of the common challenges facing many major cities.

Coastal protection

Roughly 40% of the global population lives within 100 kilometers of a coast, and roughly 10% of the world's population lives in coastal areas that are less than 10 meters above sea level, according to the United Nations. Coastal communities and local infrastructure are already facing the economic and environmental costs of flooding and erosion. These may worsen if sea levels continue to rise and if more intense storms result in more severe flooding and storm surges.

Along with plans for major projects, such as seawalls around Lower Manhattan and Staten Island (see the case study in Section 5), there will be opportunities for smaller-scale improvements to coastal protection. These include localized flood-protection barriers, levees, set-backs, erosion barriers, seawalls, embankments, storm-surge barriers and expanded drainage and pumping systems.

Some cities may target broader ecosystem protections such as barrier islands, wetlands and mangrove swamps. All of these projects should be easier to finance in major cities in developed areas than in low-density or developing coastal communities, which may experience funding challenges.

Case study: making "room for the river" in the Netherlands

- Following two periods of serious flooding in the 1990s, which ran the risk of overwhelming existing dikes and required the evacuation of a quarter of a million people, the Netherlands sought new ways to manage its flood risk.
- The government began implementing the "Room for the River" project in 2007 to do just that.
- Rather than reinforcing or replacing existing dikes to manage discharge volumes of nearby rivers, the program prioritized giving the rivers more space, for example by transforming agricultural land into floodplains. Expanding the floodplains also generated new parks and recreational areas.
- The program was implemented through roughly 30 projects over approximately 12 years, with a budget of EUR2.3 billion (roughly US$2.6 billion) funded by the public sector.

Resilient construction

Making buildings more resilient to climate change can facilitate economic activity and make cities more attractive destinations, particularly for people who are vulnerable to climate change elsewhere. Municipal authorities often own significant amounts of urban real estate, such as public buildings, housing developments, schools, hospitals and transportation terminals. This offers opportunities to innovate and experiment with climate-friendly building codes and zoning rules.

Buildings can be structured or upgraded to withstand flooding and storms by using designs and materials that are better able to withstand stronger winds, and by features such as placing key mechanical and electrical systems well above likely flood levels. Developments featuring trees, urban parks, permeable surfaces and walkways that shelter pedestrians should help to enhance the broader climate resilience of cities as well as contribute to carbon reduction efforts.

Even without formal government requirements such as new building codes in place, cities may see an economically driven expansion of energy-efficient and "green" buildings. These typically feature some combination (or all) of passive heating and cooling systems, more effective insulation, better ventilation, low-energy lighting, automatic lighting or heating timers, motion sensors, green or blue roofs, rainwater collection and water-flow controls.

Water and waste management

Climate change may result in both too much and not enough water in cities: too much because rising sea levels and storms can cause extensive flooding; too little because droughts and storms can reduce the availability or degrade the quality of municipal water supplies. Salinization of groundwater is also a risk on the coasts.

These environmental pressures may drive cities to install water-efficient plumbing, rainwater-harvesting systems, more efficient water-treatment plants, grey-water irrigation, desalination projects and drought-tolerant landscaping in order to be more resilient to climate change.

If sea levels do rise and storms intensify, some existing sewer and wastewater systems will have trouble managing the resulting rainfall and runoff. Here cities can benefit from more permeable surfaces, more "green and blue" spaces with land covered by vegetation or water and systems of "dual drainage" that utilize streets and open spaces as well as sewers to absorb flooding. China for instance has a "sponge city" initiative underway to prevent flooding, control runoff and improve the quality and quantity of drinking water.

Case study: upgrading flood management in Manila

- Typhoons and other tropical storms make torrential rains and flooding common in Manila. Heavy rainfall is exacerbated by inadequate and blocked drainage and pumping systems. Storms often cause the evacuations of thousands of people, as well as deaths, property damage and disruption of economic activity.
- In 2012 the Philippines government, with help from the World Bank, launched a Flood Management Master Plan for Metro Manila.
- In 2017 the government, the World Bank and the Asian Infrastructure Investment Bank approved funding for the Master Plan's first major project, the US$500 million Metro Manila Flood Management Program. The goal is to reduce flooding in 56 areas, benefiting at least 1.7 million people.
- The project has four parts:
    - Modernizing drainage, by constructing new pumping stations and modernizing existing ones.
    - Minimizing solid waste in waterways, by improving collection and thus reducing waste in waterways.
    - Participatory housing and resettlement, by relocating and providing rental support to people whose homes will be affected by the work.
    - And project management and coordination, by providing further support to people who relocate.

Energy resilience

Electricity grids are vulnerable to heat, flooding, storms and winds. Higher temperatures reduce the efficiency of power plants and can reduce the capacity of transmission lines, even as they increase the demand for air conditioning.

Protecting the electricity supply may require upgrading and hardening grids; some power lines may need to be buried to insulate them from the impact of storms. Solutions like distributed generation can make systems more resilient in the face of storms or outages.

Other opportunities in electricity generation, storage and management include local electricity storage (for instance, "behind-the-meter" battery storage in commercial and residential buildings), the broad roll-out of solar panels on urban buildings and the use of local alternative power sources (such as thermal energy and waste-to-energy processes). Moreover, "smart grids," which help manage energy usage in periods of stress, and "smart metering," which encourages off-peak consumption, may be helpful.

Redundancy and reliability of supply will be critical, not only because higher temperatures are likely to increase demand for electricity, but also because the growth in demand for renewable sources of electricity could result in intermittent or uneven supply. In fact, renewable energy sources themselves may be vulnerable to the impact of climate change, if droughts or changing weather patterns reduce the availability of water for hydropower, or if broader climate change reduces the potential of wind power.

Case study: making the US power grid more resilient to weather

- The electricity grid in the US consists of high-voltage transmission lines, local distribution systems and power-management and control systems that have been built over roughly 100 years.
- Most of the grid is privately owned by for-profit utility companies. Since public utilities have a natural monopoly in the market, both federal and local government agencies regulate electricity rates and operating practices.
- The US Department of Energy (DOE) indicates that severe weather is the single leading cause of power outages in the US; it estimates that between 2003 and 2012, nearly 680 power outages, each affecting at least 50,000 customers, occurred due to weather events.
- As a result, the American Recovery and Reinvestment Act of 2009 allocated $4.5 billion in government funding to the DOE for investments in modern grid technology, with the aim of increasing the resilience and reliability of the grid in the face of severe weather.
- Some of this funding has gone toward "smart grid" technology that utilizes remote control and automation to better monitor and operate the grid. This type of technology includes advanced grid sensors and distribution circuits with digital technology.

Transportation systems

Making transportation systems more resilient to climate change may be especially costly. Bridges may need to be reinforced to withstand higher winds or destructive flooding, while tunnels may require improved drainage. Airports too can be at risk, whether because tarmacs buckle at high temperatures, because floods or storms render runways and terminals inoperable or because power outages make air traffic control unavailable. Railways and roads face similar risks.

In addition to strengthening physical infrastructure, or in some cases relocating it, cities may need to make investments to improve the availability and usefulness of low-carbon and low-pollution forms of transport. For the uptake of electric vehicles to rise dramatically, for example, cities will need to install an extensive network of public charging stations. Bike-sharing programs, dedicated bike lanes and pedestrianized zones can help to reduce vehicle traffic and pollution.

Streets can be made more pedestrian-friendly, with safer crossings, upgraded sidewalks, better lighting, more trees and overpasses or underpasses across busy intersections. Public transport can be upgraded, for instance by rationalizing routes and improving interconnections, and by improving temperature controls or shelter from wind and rain. Many of these efforts are likely to aid in reducing net carbon emissions as well as in strengthening resilience.

Communications

Much of today's communications technology may seem intangible, but the reality is that cell towers, data centers, phone lines, cable lines and other important elements of the communications infrastructure are indeed tangible and are often made of materials, like metal and plastic, that are susceptible to heat or water.

For example, when Hurricane Sandy hit New York City in 2012, flooding in Lower Manhattan rendered miles of copper wiring for cable access useless. Some telecommunications providers began using fiber optics – which is more resilient to water than legacy copper – as a more resilient alternative.

Ensuring that the data centers that underpin the cloud are located in cool, dry areas (and away from risks of flooding or forest fires), or that the equipment itself is made more resilient to heat may also help. Ensuring multiple points of connectivity, such that if one is compromised others are available, would also enhance communications resilience.

Soft infrastructure

Beyond these categories of "hard" infrastructure, cities may also need to develop their "soft" infrastructure. This can mean expanded health outreach services, educational efforts and stronger social-safety-net programs (for instance a broader network of storm shelters or more cooling centers for hot days).

Some of these will require investments in technology and data, such as building integrated transport apps for residents. Coordinated disaster planning should incorporate police, fire departments, hospitals, social services, transportation authorities, civic leaders – and plenty of practice exercises.

5. Financing urban adaptation is likely to require an "all-of-the-above" approach

All of these challenges lead to a critical question: how can cities finance the extensive adaptation efforts that are likely to be needed? The answer to this question will differ depending on the resources available to the specific city in question – but in general, most cities will need to rely on multiple sources of funding, taking an "all-of-the-above" approach to their climate change adaptation financing needs.

It's difficult to put a dollar figure on the scope of the need, for two primary reasons: First, there isn't necessarily a clear delineation between, on the one hand, investments made specifically to counter or stave off the effects of climate change and, on the other hand, business-as-usual new construction or infrastructure upgrades that take advantage of environmentally-friendly and resilient modern technologies and materials. Second, as we've discussed, uncertainty around the trajectory and pace of climate change make future needs difficult to anticipate in advance – and this uncertainty may even increase the cost of adaptation efforts if investors factor in an associated risk premium.

Yet it *is* clear that urban adaptation could drive one of the largest infrastructure build-outs in history. It's also clear that most cities do not have the finances to do this alone. Potential sources of financing for urban adaptation include:

- **Public-sector financing**, whether from local tax revenues, municipal bonds or central-government funds, including direct government financing of projects and land-value capture strategies.
- **Private-sector financing**, including green bonds, commercial bank loans and direct investments from institutional investors, particularly those seeking long-duration assets to offset their long-duration liabilities.
- **Public-private partnerships** (PPP) and **private finance initiatives** (PFI).
- In emerging economies, **international financial institutions** such as the World Bank and regional development banks.
- **Insurance**, which can be designed to reduce moral hazard and to encourage innovative adaptation projects.

From a financing standpoint, there are two principal challenges regarding large-scale and long-term infrastructure projects. The first is the timing mismatch: infrastructure assets typically have a useful life spanning several decades, but the up-front construction costs are incurred over a much shorter timeframe. Governments will be hard-pressed to finance such projects out of current revenues. The second involves efficiency: governments typically have limited expertise in evaluating the risk of, constructing and operating complex infrastructure projects.

Some projects may be more attractive to private-sector financing because they involve user fees that can be priced at market levels, or charges that can be recouped through rate increases or assessments. These types of projects may include construction, power, telecommunications, airports and toll roads.

Other projects will need to draw on different sources of funding. This may be the case for coastal protection programs, public transport, non-toll roads, municipal water and sewage systems and outdoor spaces including public forests and parks, as examples. In these instances, revenue streams may not be clearly attached to the project.

Direct government financing

Some adaptation projects, particularly those that don't require expensive up-front construction – such as improvements in energy efficiency or flood-proofing of existing public buildings – can be financed directly by the government. Funding can be provided through direct grants or disaster-relief funds (in the latter case, ideally with conditions that improve the climate resilience of the resulting construction).

Case study: protecting New York City from storms and higher sea levels

- Hurricane Sandy in 2012 caused roughly $70 billion of damage across the eastern seaboard of the United States, with flooding and storm surges affecting much of New York City. As a result, the city now has several projects in design or in progress to protect the city against future storms and floods.
- These include a US Army Corps of Engineers project to defend Staten Island by building more than five miles of levees, floodwalls and a buried seawall/armored levee, supplemented by interior drainage improvements. The goal is to make Staten Island able to withstand a once-in-a-300-year flood.
- The Staten Island project is estimated to cost $615 million and will be funded by the public sector, with New York City to contribute roughly 10.5% of the cost, New York State to contribute 24.5% and the remaining 65% to come from federal funds. The project received its first funding commitment in 2017 and the remainder in 2019. It is estimated to break ground in 2020 and to be completed roughly four years later. The project was delayed by the need for federal legislation authorizing the use of federal land for the seawall.
- The separate East Side Coastal Resiliency Project is designed to protect the east side of Manhattan by raising its coastline. The project is estimated to cost $1.45 billion and to be completed by 2023. The project faces objections to its plans to close a riverside park during construction.
- In addition, the mayor of New York has announced a $10 billion plan to protect lower Manhattan from rising sea levels and flooding by extending the shoreline into the Hudson River and the East River. Funding for and the timing of this project are currently unresolved.
- These examples demonstrate some of the inherent complexities, financing needs and timelines associated with building resilience in urban areas – even in a city with ample economic resources and a dense population.

Municipal bond markets

In the US, state and local governments can turn to the municipal bond market. Municipal bonds can be repaid through a dedicated revenue stream – such as user charges on toll roads or a surcharge on water bills – or can be "general obligation bonds," which are repaid through income or property tax revenues (and may require voter approval). In some cases, surcharge revenues can be securitized. While municipal bonds can be a highly effective means of financing adaptation projects, the market is largely limited to the US, and even there, not all local governments have a track record of raising municipal debt and therefore may lack a requisite credit rating.

Green bonds

Some cities, sovereigns and supranationals (such as multilateral development banks) are turning to "green" bonds or the broader universe of "climate-aligned" and "sustainability" bonds. The not-for-profit Climate Bonds Initiative (CBI) indicates that growth in the overall issuance of green bonds has accelerated in the past few years and that the average deal size has risen over time. In emerging markets, the CBI indicates that green-bond proceeds have gone to finance low-carbon buildings, transportation, sustainable land use and sustainable agriculture, forestry and fisheries (though renewable energy remains the overwhelming focus). The "green" or "sustainable" label may make these bonds more attractive to certain types of investors, such as impact funds.

Case study: using municipal bonds to finance adaptation across the US

- Several US states and municipalities have issued municipal bonds – both general obligation bonds and revenue bonds – to finance major infrastructure adaptation projects. Among them:
- Miami's Miami Forever Bond program, approved in 2017, allocates nearly $200 million for climate-related infrastructure and capital improvements in storm-water and flood management.
- A year after 2017's Hurricane Harvey, Houston voters approved a $2.5 billion bond for more than 200 flood-control projects.
- In 2018, San Francisco voters approved a $425 million general obligation bond, supported by an increase in property taxes, in part to finance the retrofitting and reinforcing of the city's 100-year-old Embarcadero seawall.
- Washington DC's Water and Sewer Authority issued a $25 million "environmental impact bond" in 2016 to finance green infrastructure designed to prevent rain and storm-water runoff from overwhelming the city's sewer system. The bond includes a contingent payment that reflects the effectiveness of the project in reducing runoff and includes a risk-sharing provision if it does not meet certain targets.

Land-value capture strategies

Cities can also turn to land-value capture strategies to generate revenues that will support adaptation projects. They can sell ownership or development rights to fund infrastructure projects, sometimes as part of a mixed public/private development (such as the right to build apartments near a new rail or subway station). Or they can provide land for development and securitize the future lease payments.

Municipal governments can also access some of the value of land appreciation – especially in fast-urbanizing cities – through property taxes, transfer taxes or capital gains taxes, depending on what is most effective in the local environment. In some countries, capturing the value of land appreciation effectively may require broader reforms to tax laws and tax collection.

Public-private partnerships and private finance initiatives

Many major infrastructure projects are financed through public-private partnerships (PPP) and private finance initiatives (PFI), which, as their names suggest, combine public and private financing. A PPP or PFI can both reduce risk (by incorporating government guarantees or backstops) and improve efficiency (by drawing on private-sector expertise in construction, operations and maintenance). Typically, the government guarantees minimum payments to the private sector builder/operator (with additional performance-based payments) and designs the concession so that investors primarily face sovereign repayment risk on these minimum payments.

In general, PPP or PFI projects are typically designed as follows:

- The government structures the project and the bidding process, sometimes with the assistance of an international financial institution (IFI) such as the World Bank or a multilateral development bank. Key concerns are value for money and the need for the private-sector bidder to bear some of the construction risk by holding an equity stake in the project.
- As part of the tender, the government guarantees certain payments to the operator of the asset. These can be generated from the asset's cash flows, or in the case of assets that don't have direct cash flows or have unclear visibility, through an "availability payment" that is independent of the use or pricing of the asset. Multilateral institutions can also provide credit guarantees or insurance for political risk.
- The successful private-sector bidder (or in some cases multiple bidders) builds, operates and maintains the asset for a fixed concession period. In some cases, the bidder also owns the asset for this period and then transfers it to the government at the end of the term.
- The debt that finances most of the construction comes from several types of investors, principally IFIs, export credit agencies, commercial banks or, increasingly, institutional investors. The long-dated assets draw investors with long-term liabilities, including insurance and pension funds. From an investment perspective, the stable cash flows, good visibility and limited fluctuation can make these investments attractive, particularly for long-duration investors. The private sector may bear some of the construction risk – but it is the equity holders rather than the debt holders who do so.

Case study: bolstering transportation resilience through a public-private partnership

- Given flooding risks stemming from rising sea levels and storm surges, the national government of an emerging economy decides to construct a new toll road at a higher elevation than existing transportation routes.
- The toll road project connects two major cities and covers several hundred miles of land. In addition to its greater climate resilience, the project is likely to support economic growth in the major cities and to encourage growth in the less-developed areas through which the road passes.
- The national government apportions some federal tax revenues as initial financing for the project, but domestic political dynamics limit its ability to provide additional funding.
- The government thus turns to the private sector for the remainder of the financing, creating a public-private partnership (PPP). A regional development bank contributes its expertise in structuring the terms of the PPP and running the bidding process.
- Under the terms of the PPP agreement, private-sector companies (often a consortium) contract with the government to build, operate and maintain the roads. The private sector bears the risks associated with the construction and, as per the tender, has an equity stake as "skin in the game" that will incentivize it to meet specified construction, operational and maintenance targets.
- The consortium issues a bond to finance the project, collateralized by the toll fees from the roads and backstopped by a government guarantee for a minimum payment to the road operator. This guarantee reflects the uncertainty around the future revenue stream of this new project and helps to reduce the cost of capital.
- Private-sector investors may include commercial banks, as well as pension funds, insurance companies and sovereign wealth funds looking for long-term assets.
- International financial institutions may also provide subsidized loans or guarantees, both of which reduce the risk profile of the project.

International financial institutions

International financial institutions (IFIs) can play several roles in PPP or PFI projects. They often provide technical assistance in the structuring and bidding processes. They can participate as direct lenders (at subsidized interest rates), as guarantors, as providers of a liquidity facility or as the "lender of record" in a way that reduces repayment risk for private-sector lenders. In some cases they will provide financing to a dedicated government agency that is established solely to build and operate infrastructure. IFIs also have programs to improve the creditworthiness of cities seeking to borrow, as well as broader institutional capacity-building programs that help develop administration, planning and tax collection.

Case study: using public-private partnerships to develop ports

- A municipality plans to replace its outdated, state-owned and state-operated port with a new facility that will meet several needs: becoming more resilient to rising sea levels, improving the environmental footprint of its operations, handling more capacity and improving productivity.
- Under the commonly used "landlord" model, the government will own the land and basic infrastructure, while the private sector will manage the port's operations and terminals and maintain the infrastructure.
- The city chooses an "availability-payment public-private partnership." Under this structure, the city contracts with a private-sector consortium that builds and operates the port and is responsible for maintenance. This consortium is capitalized with investors' equity and with debt raised from banks or capital markets; it may take a bridge loan to cover the construction costs.
- The government contributes some funding toward construction and commits to paying the consortium a fixed "availability fee" for several decades. It may also offer credit support to the project.
- The contract includes some provisions for political risk – potentially via credit support from the government – and for foreign-exchange risk.
- The public sector avoids the up-front costs of construction and achieves greater budget stability through the fixed payments. It also benefits from the private sector's expertise, which improves the port's productivity – which is important given that, according to this contract's terms, the city still owns the rights to all of the port's revenues.

The role of insurance

Insurance can also help to finance adaptation efforts. First, government-provided insurance in particular can support adaptation by pricing risk accurately and *not* providing coverage that encourages moral hazard. While subsidized insurance for property in flood- or fire-prone areas is often politically popular, it encourages building and post-disaster rebuilding in areas that remain demonstrably vulnerable to climate change, particularly flooding and wildfires.

Withdrawing subsidies or imposing stricter constraints on building and rebuilding – for example requiring that flooded homes be redesigned rather than simply rebuilt – could help to reduce the moral hazard problem. In the process this could also allow funds to be directed to more effective adaptation opportunities. Subsidized insurance payouts and government disaster funds could be made contingent on local communities taking verifiable steps to strengthen local climate defenses.

Second, insurance policies can also have provisions that reduce premiums to encourage companies or municipalities to undertake adaptation projects, such as barrier islands, support for coral reefs, wetlands or forest management. Making flood or other disaster insurance mandatory in certain areas would help to spread risk and to encourage more pre-emptive adaptation steps.

Moreover, innovative insurance products can be developed to help protect areas from the impact of climate change. Markets for crop insurance, catastrophe bonds and resilience bonds could offer lower premiums for municipalities that take active steps to avert the worst effects of climate change.

"Soft" infrastructure

Whatever the mix of funding, soft infrastructure will play an important role. In the context of funding infrastructure projects, soft infrastructure includes legal and market features such as domestic capital markets, credit ratings agencies, supportive financial regulation, up-to-date land registries, enforceable property rights, strong tax administration, transparent procurement and bidding systems, risk-management tools, zoning, regulation and integrated urban planning. Creditworthiness may be a key concern for cities without a long track record of borrowing – potentially exacerbated by an environment where this soft infrastructure is weak.

Appendix A: The risks of a warmer world

Bearing in mind the many uncertainties about the timing, scope and magnitude of climate change, we note that the potential negative consequences could include:

- **More frequent, more intense and longer-lasting heatwaves** that harm human health, especially among vulnerable populations, reduce productivity, disrupt economic activity and hurt agriculture. According to the IPCC, it is "virtually certain" that there will be more frequent hot and fewer cold extreme temperature days, and it is "very likely" that heat waves will occur with higher frequency and longer duration, particularly in the tropics. Higher surface temperatures could exacerbate the warming process by causing permafrost to melt, releasing further methane and CO2 into the atmosphere.
- **More frequent destructive weather events**, including storms, winds, flooding and fires. Some regions could see more precipitation, and tropical cyclones bringing heavy rain and winds could become more frequent or more intense (or both). The maps below show (in shades of blue) our estimates of how flooding could affect some of the world's major coastal cities, including New York, Tokyo and Lagos. Other major low-lying coastal or already flood-prone cities include Shanghai, Dhaka, Mumbai and Karachi – each of which has a population of 15 million people or more (see Exhibits 7 and 8 below and Appendix B for our methodology). Yet in other areas, droughts are projected to become more frequent and more intense.
- **Changing disease patterns,** which could adversely affect human health. Warmer temperatures could cause disease vectors to migrate from the tropics to regions where people have less immunity; this is true not only for viruses like malaria and dengue fever but also for water-borne and food-borne diseases. Air pollution and increased ground-level ozone could also increase occurrences of asthma and respiratory diseases.
- **Shifting agricultural patterns**, affecting the availability of food. Warmer temperatures and shifting precipitation patterns could reduce yields and nutritional quality as well change growing seasons and agricultural zones around the world. Livestock could be affected by higher temperatures and reduced water supplies. Ocean acidification is likely to put stress on aquatic populations and affect current fishing patterns. Some of these changes are already underway. Some climate scientists, for example, estimate that coral reefs will be all but extinct over the course of the century due to ocean acidification.
- **Pressure on the availability and quality of water**, with widespread potential consequences. The World Health Organization (WHO) estimates that half of the world's population will live in water-stressed areas as soon as 2025. Even in non-stressed areas, the quality of surface water could deteriorate as more rain and storms drive erosion and the release of toxins. These dynamics could affect everything from the availability of drinking water for people to a shortage of water for livestock and crops (with negative effects for the food supply) to decreases in

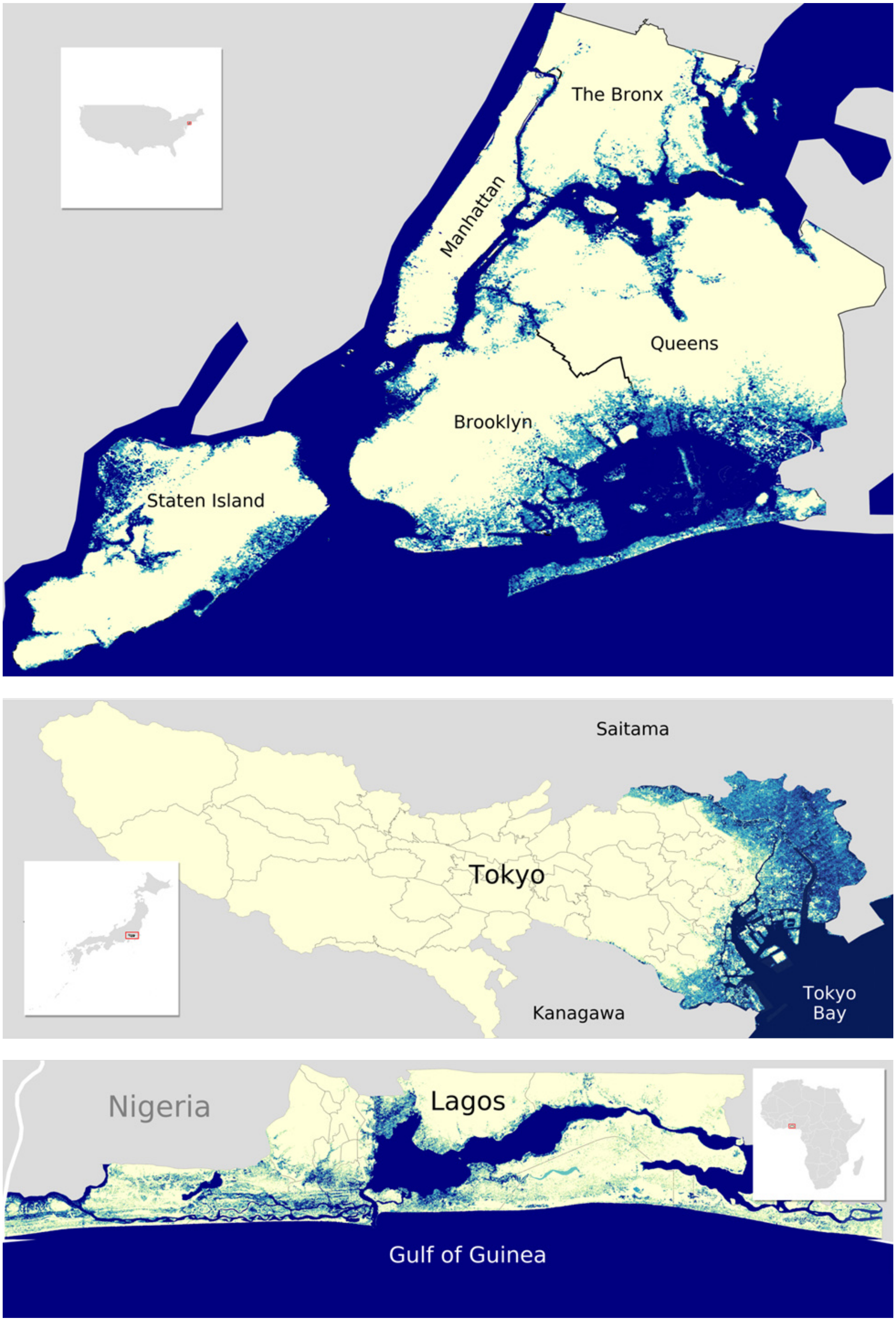
hydroelectric power generation (which itself is expected to play a role in countering carbon accumulation over the long term).

Exhibit 7: Populations and elevations of major coastal cities

Urban Agglomeration	City Population 2020 (MM)	Avg. Elevation (m)
Tokyo	37.4	35
Shanghai	27.1	11
Dhaka	21.0	10
Mumbai	20.4	23
New York-Newark	18.8	18
Karachi	16.1	33
Buenos Aires	15.2	15
Lagos	14.4	11
Manila	13.9	13
Rio de Janeiro	13.5	67
Los Angeles-Long Beach-Santa Ana	12.4	83
Shenzhen	12.4	51
Chennai	11.0	13
Jakarta	10.8	17
Lima	10.7	180
Bangkok	10.5	9
Seoul	10.0	78
London	9.3	32
Luanda	8.3	37
Hong Kong	7.5	80
Surat	7.2	11
Dar es Salaam	6.7	23
Houston	6.4	21
Miami	6.1	9
Singapore	5.9	21
Qingdao	5.6	22
Barcelona	5.6	76
Fukuoka	5.5	19
Alexandria	5.3	1
Chittagong	5.0	11
Sydney	4.9	28
Boston	4.3	15
Rome	4.3	49
Seattle	3.4	44
San Francisco-Oakland	3.3	46
Athens	3.2	185
Dublin	1.2	44
Amsterdam	1.1	-1

Source: United Nations, NASA's GDEMv2, Goldman Sachs Global Investment Research

Exhibit 8: Rising sea levels and storm surges put parts of New York City, Tokyo and Lagos at risk of flooding



Source: NASA's SRTMv3, Goldman Sachs Global Investment Research (see Appendix B for our methodology)

Appendix B: Explaining our methodology

We provide a high-level overview of climate change impact leveraging a variety of peer-reviewed publications and widely accepted data sources within the scientific community. Exhibit 9 provides a complete list of data sets. Additionally, we process all data through our proprietary geospatial framework for better visibility into regional variations within the data as well as a further exploration of interplay between data sets.

To study the change in global temperature (Exhibits 1-4 above), we consider the HadCRUT4 and GISTEMP datasets, setting the change in temperature (in °C) relative to the average temperature anomaly in the 1850-1900 period. For the geospatial representation of the data, we set the absolute scale as the average global value of the two datasets and leverage the gridded data from the GISTEMP dataset to display regional variations, averaging data points across a five-year period to minimize effects from year-to-year fluctuations. All maps are initialized using a standard reference frame (EPSG:4326), and missing data are filled using a linear interpolation (they account for fewer than 0.25% of all data points per year).

Our sea-level rise impact analysis (Exhibit 8 in Appendix A) leverages the combination of UN population estimates and city locations with global elevation data sets. To evaluate elevation, we use both SRTMv3 and ASTER GDEMv2, which is a product of NASA and Japan's Ministry of Economy, Trade and Industry (METI). We first identify all cities within 100 miles of the ocean worldwide, and of these we identify a subset including the 25 most populous. For Tokyo, New York City and Lagos we use municipal Geographic Information System (GIS) data to identify the city boundaries.

For the average elevation measurement, we use a simplified topology of a circle with a five-mile radius with its center coordinates from the UN's world city population dataset to approximate the city area. Within this area we measure the mean value of all gridded elevation data points, excluding any area lying on water, for both the GDEMv2 and SRTMv3 datasets, and use the mean of these two values as the average elevation for each city. To calculate exposure to sea-level rise, we use the high resolution SRTMv3 gridded elevation data to identify low-lying areas. These areas represent both areas with an elevation lower than the modeled rise in sea level as well as those with high sensitivity to flooding. The maximum threshold is representative of historical upper storm surge levels from significant hurricanes in coastal areas globally.

Exhibit 9: Datasets used in our proprietary analyses

Dataset Name	Description	Agency	Version
HadCRUT4	Historical worldwide temperature anomaly measurements	Climatic Research Unit, University of East Anglia	4.6.0.0.median
GISTEMP	Historical worldwide temperature anomaly measurements	NASA Goddard Institute for Space Studies (GISS)	GISTEMP v4, ERSSTv5, 1200km smoothing, GHCN v4
Vector map data	Country shape data	Natural Earth	Version 2.0.0
ASTER GDEM	Worldwide elevation	NASA, METI	GDEM Version 2
SRTM	Worldwide elevation	NASA	SRTM NASA Version 3
WUP2018-F12	World city population estimates	United Nations, Population Division, World Urbanization Projects	2018 Revision

Source: Goldman Sachs Global Investment Research

Selected sources

China Daily, "Xiongan New Area's master plan: highlights" (April 2018)

City of Miami, "Miami Forever Bond Project to Mitigate Effects of Sea Level Rise" (March 2019)

Climate-ADAPT, "Room for the River Waal – protecting the city of Nijmegen" (April 2016)

"Copenhagen Climate Adaptation Plan" (2011)

European Environment Agency, "Interview – The Dutch Make Room for The River" (February 2019)

Houston Chronicle, "Harris County voters pass $2.5 billion flood bond one year after Harvey" (August 2018)

Intergovernmental Panel on Climate Change (IPCC), "Climate Change 2014 Synthesis Report" (2014)

IPCC, "Global Warming of 1.5°C" (October 2018)

IPCC, "IPCC Special Report on Climate Change and Land" (August 2019)

New York State Department of Environmental Conservation, "Coastal Storm Risk Management Projects"

President's Council of Economic Advisors and U.S. Department of Energy, "Economic Benefits of Increasing Electric Grid Resilience to Weather Outages" (August 2013)

San Francisco Chronicle, "SF's Embarcadero seawall measure wins easily" (November 2018)

United Nations, "Factsheet: People and Oceans" (June 2017)

WYNC, "A Great Wall of Staten Island to Ward Off Hurricanes" (August 2015)

World Bank, "Managing floods for inclusive and resilient development in Metro Manila" (October 2018)

World Economic Forum, "Global Future Council on Cities and Urbanization"

XinhuaNet, "China approves 2018-2035 master plan for Xiongan New Area" (January 2019)

Disclosure Appendix

Disclosures

This report has been prepared by the Global Markets Institute, the research think tank within the Global Investment Research Division of The Goldman Sachs Group, Inc. ("Goldman Sachs").

Prior to publication, this report may have been discussed with or reviewed by persons outside of the Global Investment Research Division. While this report may discuss implications of legislative, regulatory and economic policy developments for industry sectors and the broader economy, may include strategic corporate advice and may have broad social implications, it does not recommend any individual security or an investment in any individual company and should not be relied upon in making investment decisions with respect to individual companies or securities.

Distributing entities

The Global Investment Research Division of Goldman Sachs produces and distributes research products for clients of Goldman Sachs on a global basis. Analysts based in Goldman Sachs offices around the world produce equity research on industries and companies, and research on macroeconomics, currencies, commodities and portfolio strategy. This research is disseminated in Australia by Goldman Sachs Australia Pty Ltd (ABN 21 006 797 897); in Brazil by Goldman Sachs do Brasil Corretora de Títulos e Valores Mobiliários S.A.; Ombudsman Goldman Sachs Brazil: 0800 727 5764 and / or ouvidoriagoldmansachs@gs.com. Available Weekdays (except holidays), from 9am to 6pm. Ouvidoria Goldman Sachs Brasil: 0800 727 5764 e/ou ouvidoriagoldmansachs@gs.com. Horário de funcionamento: segunda-feira à sexta-feira (exceto feriados), das 9h às 18h; in Canada by either Goldman Sachs Canada Inc. or Goldman Sachs & Co. LLC; in Hong Kong by Goldman Sachs (Asia) L.L.C.; in India by Goldman Sachs (India) Securities Private Ltd.; in Japan by Goldman Sachs Japan Co., Ltd.; in the Republic of Korea by Goldman Sachs (Asia) L.L.C., Seoul Branch; in New Zealand by Goldman Sachs New Zealand Limited; in Russia by OOO Goldman Sachs; in Singapore by Goldman Sachs (Singapore) Pte. (Company Number: 198602165W); and in the United States of America by Goldman Sachs & Co. LLC. Goldman Sachs International has approved this research in connection with its distribution in the United Kingdom and European Union.

European Union: Goldman Sachs International authorised by the Prudential Regulation Authority and regulated by the Financial Conduct Authority and the Prudential Regulation Authority, has approved this research in connection with its distribution in the European Union and United Kingdom.

Goldman Sachs conducts a global full-service, integrated investment banking, investment management and brokerage business. It has investment banking and other business relationships with governments and companies around the world, and publishes equity, fixed income, commodities and economic research about, and with implications for, those governments and companies that may be inconsistent with the views expressed in this report. In addition, its trading and investment businesses and asset management operations may take positions and make decisions without regard to the views expressed in this report.

© 2019 Goldman Sachs.

No part of this material may be (i) copied, photocopied or duplicated in any form by any means or (ii) redistributed without the prior written consent of The Goldman Sachs Group, Inc.