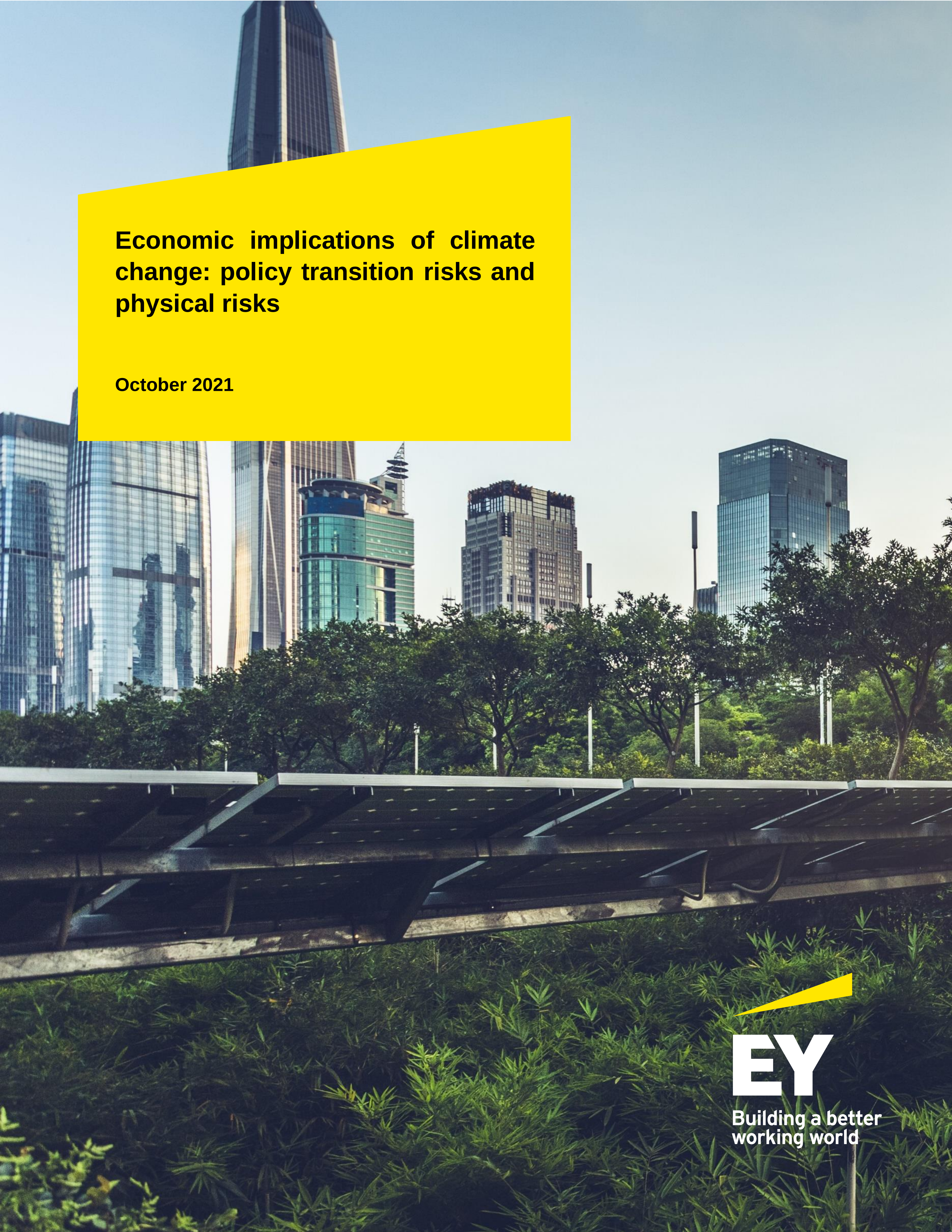


Economic implications of climate change: policy transition risks and physical risks

October 2021

Building a better working world

Contents

I. Introduction

In December 2015, at the United Nations Climate Change Conference (COP21), 196 parties adopted the Paris Agreement — an international treaty with a goal of combating climate change and adapting to its effects.[1] The treaty aims to limit warming to well below 2°C, preferably to 1.5°C, as the current global warming stands at about 1.1°C from 1850–1900 to 2010–19.[2] The current global warming levels have already led to compound extreme weather events and increased physical risks across many locations around the world, which prompted the adoption of the treaty.[3]

We look forward to the 26th United Nations (UN) Climate Change Conference of the Parties (COP26) in Glasgow during October–November 2021. The COP26 summit aims to accelerate action toward the goals of the Paris Agreement and the UN Framework Convention on Climate Change. The window for achieving that goal is closing and this makes COP26 — at which the parties will set forth the steps that they will take to hold the temperature rise to this previously agreed level — potentially the most significant climate event since the signing of the 2015 Paris Agreement.

If the long-term goals set by the Paris Agreement, such as the limit on warming levels, are not met, the global community will be subject to potentially devastating physical risks. However, meeting the Paris Agreement will necessitate policy paths that move economies, businesses and individuals to more environmental friendly practices. These policy paths may pose challenges for businesses and economies. That is, policies that mitigate climate change will impact both the amount and types of economic activities businesses can profitably pursue.

Inaction has its own costs. Extreme weather events of the past year — from heat waves to floods and wildfires — are evidence of the warming planet and demonstrate some of the costs of business as usual. These costs include increasingly frequent, climate-related disruptions to business operations, including the impacts on and from overburdened power grids, disruptions to transportation channels and supply chains, as well as employee health issues from increased heat and pollution.

It is critical for businesses, policymakers and other stakeholders to understand the economic implications of both the policy transition and physical risks associated with climate change. This report provides an overview of the implications of the policy transition risks associated with addressing climate change, as well as the physical risks that arise from overlooking climate change.

<u>Policy transition risks</u>

Policies implemented to combat climate change will impact the amount and types of economic activity in the global economy, create financial risks for investors and broadly impact macroeconomic variables. While mitigating the effects of climate change is necessary to address the physical risks it poses, it is also important to understand the policy transition risks in order to protect businesses and workers.[4]

These policy transition risks are likely to vary significantly in magnitude across geographies and sectors. Examples of policies include carbon pricing strategies, such as emissions trading schemes or cap-and-trade systems. These systems set a cap on the total amount of greenhouse gases (GHGs) that can be emitted, and then distributes that limit among entities.[5] Another carbon pricing strategy is carbon taxation, which puts a price on emitting GHGs (e.g., US$25/ton).[6] A carbon tax has price certainty but not GHG emissions certainty, whereas an emissions trading scheme or cap-and-trade system has GHG emissions certainty but not price certainty. An alternative pricing approach is to subsidize green initiatives, which reduces the price of green initiatives rather than increasing the price of GHG emissions.

Physical risks

According to the Intergovernmental Panel on Climate Change (IPCC), the global surface temperature has increased over the past 50 years at a faster rate than that of any other period over the past 2,000 years.[7] The increase in carbon dioxide and other GHGs in the atmosphere has led to this warming. This has intensified the global water cycle, leading to competition for water resources and flooding, as well as increases in the frequency, and severity, of extreme weather events, including tropical cyclones and hurricanes, wildfires, heat waves and cold waves. These physical risks can have a profound effect on infrastructure, ecosystems and health, as well as on broader economies.

The global surface temperature will continue to increase unless there are significant reductions in GHG emissions, which is an objective of the Paris Agreement.[8] Notably, the current concentrations of GHG emissions will result in physical risks, even if there is a reduction in future GHG emissions. Stabilizing concentrations will limit increases in their severity.

II. Executive summary

Overview

- **Policy transition risk:** Policies implemented to combat climate change will impact the amount and types of economic activity in the global economy, create financial risks for investors and broadly impact macroeconomic variables. These policy transition risks are likely to vary significantly in magnitude across geographies and sectors.

- **Physical risk:** The increase in carbon dioxide and other GHGs in the atmosphere has led to global warming. Consequently, this has intensified the global water cycle, leading to water stress and flooding, as well as increases in the frequency, and severity, of extreme weather events, including tropical cyclones and hurricanes, wildfires, heat waves and cold waves. These physical risks can have a profound effect on infrastructure, ecosystems and health, as well as on broader economies. The current concentrations of GHG emissions will result in physical risks, even if there is a reduction in future GHG emissions. However, stabilizing concentrations will limit the upper bound of these impacts.

- **Analysis framework:** This analysis relies on the July 2021 analysis from the Network for Greening the Financial System (NGFS) — members of which include the Bank of England, the European Central Bank and the US Federal Reserve — as a starting point and builds upon it. It provides additional modeling, as well as highlights how the estimated impacts can be understood in practice.

Policy transition risk

- **Necessary carbon price:** A price on carbon is a necessary component of the policy path to limit global warming to Paris Agreement targets. Under an orderly transition to a 1.5°C temperature target, by 2030 the necessary worldwide average price may be as high as US$157/ton higher than the average projected under policies in place today.

  In the NGFS modeling, the Net Zero 2050 scenario limits global warming to 1.5°C while the Current Policies scenario assumes that only the currently implemented policies will continue. NGFS modeling estimates that, by 2030, a carbon price increase of, on average, US$157/ton across the global economy is needed to achieve the Net Zero 2050 scenario. This compares to, on average, less than US$3/ton price in the Current Policies scenario.[9]

- **Economic impact:** This level of carbon pricing, excluding any consideration of the economic benefits of reducing physical risk, is estimated to reduce the size of the global economy, as measured by gross domestic product (GDP), by 1.8% relative to the level that would occur in 2030 under the Current Policies scenario. Of the five largest world economies, India experiences the largest decrease in the level of GDP under Net Zero 2050 relative to the level under Current Policies in 2030 (2.3%), followed by China Mainland (2.2%), the United States (1.3%), Japan (1.2%) and the European Union (0.9%).

- **Real-life policy considerations:** A first-order consideration in the economic impact of carbon pricing is that it generates revenue, which inherently creates opportunities. For instance, the revenue could be used to reduce pre-existing taxes, fund additional government spending or transfers or reduce government deficits. How the revenue is used will determine both the magnitude and the sign (i.e., positive or negative) of the economic impact. That is, the economic impact of carbon pricing can be positive or negative — even when excluding any benefits of GHG mitigation via, for example, a reduction in physical climate risk — depending on how the revenue is used. An Ernst & Young LLP (EY) macroeconomic model is used to demonstrate this as well as to produce industry and subnational results.

Physical risk

- **Economic impact:** Like transition policy risk — the risks associated with implementing policies to address climate change — there are also risks associated with ignoring climate change. The impact of the temperature increase on productivity under the Current Policies scenario is estimated to decrease global GDP by 1.0% by 2030. Of the five largest world economies, the United States experiences the largest estimated decrease in GDP (1.2%), followed by Japan (1.1%), the European Union (0.7%), India (0.6%) and China Mainland (0.5%).

- **Other physical risks:** There are other notable physical risk considerations beyond the impact of temperature increase on productivity. These risks include water stress, river flooding, coastal flooding, hurricanes, wildfires, heat waves, cold waves and adverse health effects.

III. Analysis framework

This analysis relies on the July 2021 analysis from the NGFS as a starting point and builds upon it. It provides additional modeling, as well as highlights how the estimated impacts can be understood in practice.[10]

Network for Greening the Financial System (NGFS)

The NGFS is a group of supervisors and central banks aiming to promote green finance and define central banks' role in fighting climate change.[11] Its members include the Bank of England, the European Central Bank and the US Federal Reserve.[12] The existing NGFS climate modeling provides a reference framework for analyzing policy transition risk and the physical risk effects of climate change on the global economy. There are six NGFS scenarios: two orderly scenarios; two disorderly scenarios and two hothouse world scenarios. These are summarized in Table 1.

Table 1: NGFS climate scenarios

Category	Scenario	Temperature ambition	Policy reaction	Physical risk	Transition risk
Orderly	Net Zero 2050	1.5°C	Immediate and smooth	Low	Low
	Below 2°C	1.7°C	Immediate and smooth	Low	Low
Disorderly	Divergent Net Zero	1.5°C	Immediate but divergent	Low	High
	Delayed Transition	1.8°C	Delayed	Low	Medium
Hothouse world	Nationally Determined Contributions (NDCs)	~2.5°C	NDCs	Medium	Low
	Current Policies	3°C+	None-current policies	High	Low

Source: Network for Greening the Financial System, *NGFS Climate Scenarios for central banks and supervisors*, June 2021.

The two orderly scenarios assume climate policies are introduced early and become increasingly stringent over time. The Net Zero 2050 scenario limits global warming to 1.5°C; the Below 2°C scenario limits global warming to 1.7°C. In the two disorderly scenarios, climate policies are delayed or divergent across countries and sectors, thereby requiring sharper reductions in emissions than orderly scenarios, to reach the same target. The Divergent Net Zero scenario achieves the 1.5°C target like the orderly Net Zero 2050 scenario, but at a higher cost. In the second disorderly scenario — Delayed Transition — warming is limited to 1.8°C with stronger policies. In the hothouse world scenarios, only current polices continue, leading to continued warming and severe physical risk. The first hothouse scenario is Nationally Determined Contributions (NDCs), which includes all currently pledged policies. The second scenario — Current Policies — assumes that only currently implemented policies will continue.

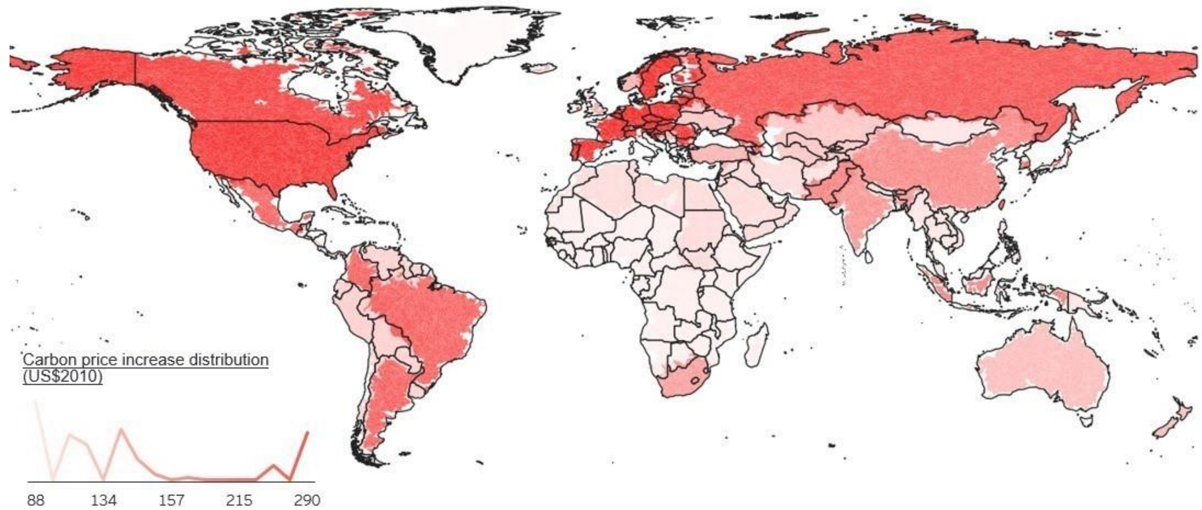
The NGFS modeling relies on three integrated assessment models (IAMs).[13] IAMs combine macroeconomic, agriculture, land use, energy, water and climate systems into a common framework, that enables the analysis of their effects on the economy and impacts on the climate. IAMs provide internally consistent estimates across economic and climate systems, making them useful for scenario analysis. These models are helpful for estimating global and regional mitigation costs, and for identifying trade-offs of sustainable development pathways.[14]

IV. Policy transition risk

Policy measures are needed to reach Net Zero 2050. Figure 1 displays the necessary increase in carbon price by 2030 for each country in the Net Zero 2050 scenario, relative to the Current Policies scenario. The NGFS modeling estimates that, by 2030, a carbon price increase of, on average, US$157/ton across the global economy is needed in the Net Zero 2050 scenario, relative to the Current Policies scenario. This compares to, on average, less than US$3/ton price in the Current Policies scenario. As seen in Figure 1, of the five largest world economies (i.e., China Mainland, India, the European Union, Japan and the United States), the largest increase in carbon price occurs in the European Union (US$290), followed by the United States (US$232), Japan (US$204), China Mainland (US$144) and India (US$97).

Figure 1: Carbon price increase by country in 2030

Net Zero 2050 relative to Current Policies

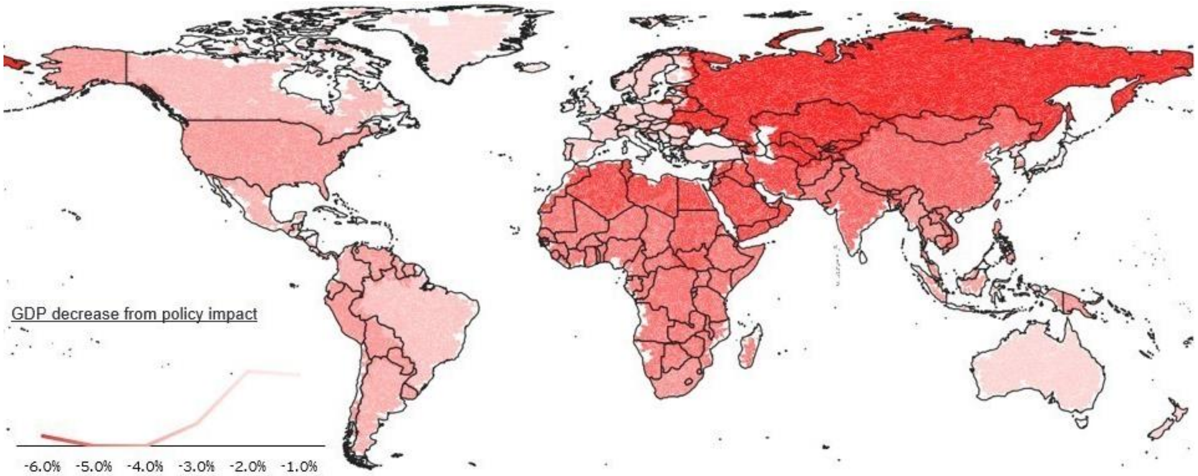


Source: NGFS; EY analysis.

Policies implemented to combat climate change will impact the amount and types of economic activity in the global economy, create financial risks for investors and broadly impact macroeconomic variables. Carbon pricing is no exception. Figure 2 displays the NGFS-estimated 2030 macroeconomic impacts of the change in carbon pricing necessary to achieve Net Zero 2050. The carbon pricing, excluding any consideration of economic benefits of reducing physical risk, is estimated to reduce the size of the global economy, as measured by GDP, by 1.8% relative to the level that would occur in 2030 under Current Policies. Of the five largest world economies, India experiences the largest decrease in the level of GDP under Net Zero 2050 relative to the level under Current Policies in 2030 (2.3%), followed by China Mainland (2.2%), the United States (1.3%), Japan (1.2%) and the European Union (0.9%).

Figure 2: Policy transition risk — percentage change in GDP by country in 2030

Net Zero 2050 level relative to Current Policies level



Source: NGFS; EY analysis.

Real-life policy considerations

A first-order consideration in the economic impact of carbon pricing is that it generates revenue, which inherently creates opportunities. For example, the revenue could be used to reduce pre-existing taxes, fund additional government spending or transfers or reduce government deficits. How the revenue is used will determine both the magnitude and the sign (i.e., positive or negative) of the economic impact. That is, the economic impact of carbon pricing can be positive or negative — even when excluding any benefits of GHG mitigation via, for example, a reduction in physical climate risk — depending on how the revenue is used.[15]

This point is illustrated, for example, in detailed EY modeling of the economic impact of carbon pricing in the United States using an EY macroeconomic model.[16] This modeling estimated the net economic impact of a budget-neutral carbon tax, where the revenue was used to either reduce pre-existing taxes, fund public infrastructure or fund a rebate to households. The reduction in pre-existing individual and capital taxes would increase the after-tax reward to work, resulting in either higher real wages or increases in the US workforce. This would also increase the after-tax return on savings and investment, which would encourage more capital investment and contribute to higher labor productivity.[17] The investment in public infrastructure would boost private-sector productivity and, consequently, increase private-sector output. The rebate to households would, on average, offset the impact of the carbon tax on household incomes.

Overall, the analysis estimated that the carbon tax — which was approximately US$50/ton across simulations — would, on net, *increase* the level of GDP relative to what it otherwise would have been when revenues are used to reduce preexisting taxes (2.1% or approximately US$3,320 per household); *increase* the level of GDP relative to what it otherwise would have been when revenues are used to fund public infrastructure (1.0% or approximately US$1,520 per household); and *decrease* the level of GDP relative to what it otherwise would have been when revenues are used to fund a household rebate (0.4% or approximately US$600 per household).[18] These estimated impacts exclude any benefits from reducing physical risk.

Notably, there are policy mechanisms other than carbon pricing through which GHG mitigation can occur. Carbon pricing, however, is generally the least-cost policy approach for a given level of emissions mitigation. For example, the same EY analysis examined the economic impact of a stylized regulatory regime, including many of the regulatory policies that the United States has used or considered in the past. The policies include: Corporate Average Fuel Economy (CAFE) standards, that require that a manufacturer's model year of vehicles meet a fleet-wide average fuel efficiency level; the Clean Power Plan, which aimed to reduce carbon emissions in the power sector; Renewable Fuel Standards, that require the motor fuel distributors to include a specific percentage of renewable fuels in their total sales; and appliance and equipment efficiency standards that set energy efficiency standards for appliances and equipment to reduce energy consumption.[19] This stylized regulatory regime, which reduced US GHG emissions by an amount identical to the approximately US$50/ton carbon taxes, was estimated to *decrease* the level of GDP in the United States by 1.1% or US$1,770 per household, relative to the level it otherwise would have been. Again, these estimated impacts exclude any benefits from reducing physical risk.

Overall, when analyzing the potential economic impact of carbon mitigation policy, it is essential to understand the implications of real-life policy considerations. Although a carbon price can serve as a useful high-level summary in modeling, real-life policy considerations can impact both the sign and magnitude of the estimated impact. Moreover, outside of the single-country context, the economic impacts of the policy scenario for a given country can importantly depend on spillover impacts of policies enacted elsewhere. For example, fossil fuel exporting countries may experience more impacts from policies in other countries than the policies adopted domestically. Finally, it is important to understand that the future is inherently uncertain and this uncertainty increases as projections go further into the future.

<u>Industry and subnational detail</u>

Policy transition risks are likely to vary significantly in magnitude across geographies and sectors. Accordingly, a key limitation of the results presented above is that there are no subnational or industry-level results. Such granular sector and subnational data are of most use to businesses, policymakers and other stakeholders when understanding the implications of policy transition risk and where it is likely to be concentrated. Businesses, for example, may have concerns regarding whether their assets or the assets of their clients and their target markets are at risk. Policymakers may be concerned about the communities that may be disproportionately impacted by mitigation policy.

The EY macroeconomic model, however, can be calibrated to match key macroeconomic results from the NGFS analyses and, in effect, downscale the results to the industry and subnational levels. The EY macroeconomic model includes a detailed modeling of industries, as well as their inter-industry linkages. Each industry differs in its relative use of capital, labor and energy inputs, as well as in the carbon content of its outputs. Each industry is responsive to the price of capital, labor and energy, as firms choose the optimal mix based on relative prices and industry-specific characteristics. Businesses and households incorporate the after-tax return from work and savings into their decisions of how much to produce, save and work.[20]

As an illustration, Table 2 displays results from the Net Zero 2050 scenario relative to the Current Policies scenario, downscaled with the EY macroeconomic model for the United States. For this simulation, the EY macroeconomic model was calibrated to match NGFS results (i.e., results presented in Figure 2). Table 2 presents results for detailed industries aggregated into high-level sectors. The largest percentage decline in industry GDP is estimated to occur in the mining industry (24%), followed by the utilities (14%); manufacturing (3%); transportation (3%); agriculture, construction and information (1%); wholesale trade and retail (less than 0.5%); and services (less than 0.5%) industries.

Even this level of aggregation masks significant economic dynamics. Underlying these estimates are more pronounced declines in parts of the mining industry (i.e., in the oil and gas extraction and coal mining industries) and the utilities industry (i.e., in fossil fuel power generation industries). Additionally, the model simulated a marked increase in the use of renewable energy power generation in the utilities industries. Ultimately, no country or industry average will completely reflect the facts and circumstances of any business or community.

Table 2: Percentage change in GDP by industry in the United States in 2030

Net Zero 2050 level relative to Current Policies level

NAICS	Industry description	% Change in GDP	Share of GDP change
11,23,53	Agriculture, construction and information	-1%	8%
21	Mining	-24%	27%
22	Utilities	-14%	17%
31-33	Manufacturing	-3%	26%
42-45	Wholesale and retail trade	*	2%
48-49	Transportation	-3%	7%
54-81	Services	*	14%
Total		**-2%**	**100%**

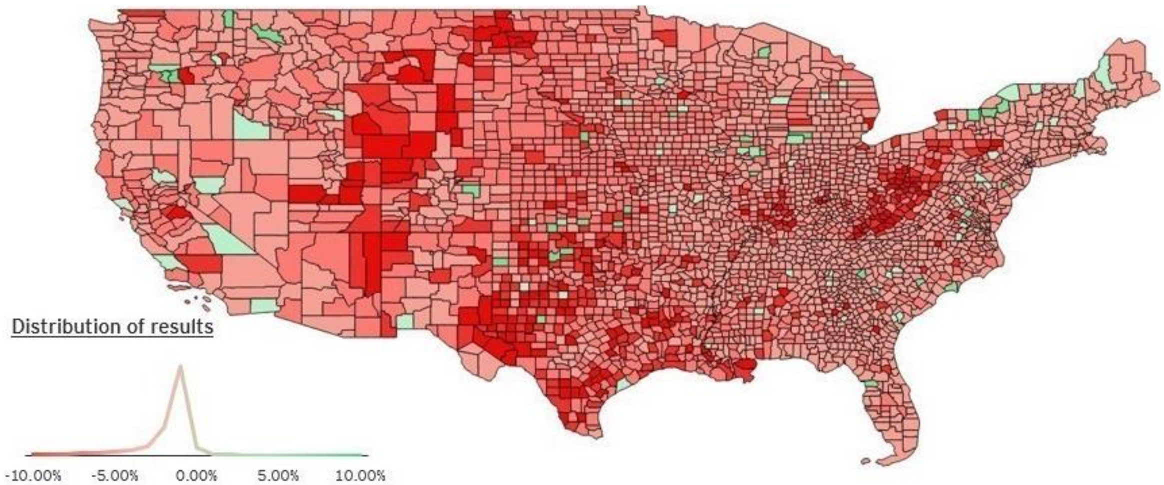
*This denotes a magnitude of less than 0.5%.

Note: Sectors are based on the North American Industry Classification System (NAICS). Figures are rounded.

Source: Network for Greening the Financial System, *NGFS Climate Scenarios for central banks and supervisors*, June 2021.; EY analysis.

Similarly, as an illustration of subnational downscaling, Figure 3 displays the percentage change in the level of GDP from the Net Zero 2050 scenario relative to the Current Policies scenario, downscaled for the United States. In particular, this analysis uses the industry results — as estimated by the EY macroeconomic model and summarized by the high-level sector in Table 2 — to examine the potential subnational impacts of the Net Zero 2050 scenario relative to the Current Policies scenario.[21] Counties with the largest declines in economic activity, for example, are often those with high concentrations of fossil fuel-related industries. These estimated impacts exclude any benefits from reducing physical risk.

Figure 3: Percentage change in GDP by county in the United States in 2030
Net Zero 2050 level relative to Current Policies level

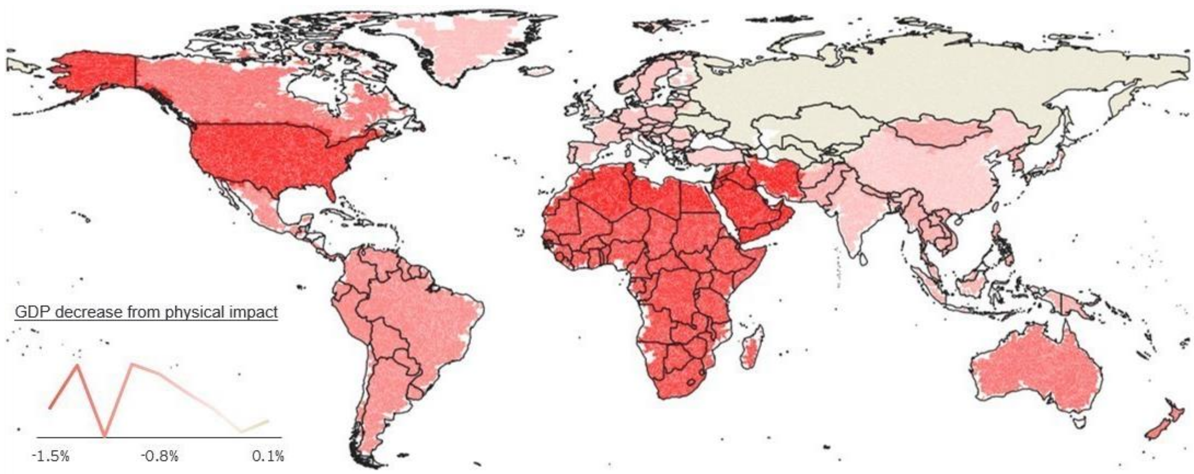


Source: NGFS; EY analysis.

V. Physical risk

Like transition policy risk — the risks associated with implementing policy to address climate change — there are also risks that arise from overlooking climate change. Figure 4 displays the economic impact of temperature increase on productivity by country. In particular, the percentage change in the level of GDP by 2030 under the Current Policies scenario is displayed. Of the five largest economies, the United States experiences the largest estimated decrease in GDP (1.2%), followed by Japan (1.1%), the European Union (0.7%), India (0.6%) and China Mainland (0.5%). Russia and countries that were in the former Soviet Union are the only countries with an estimated increase in GDP due to temperature increase.

Figure 4: Physical risk — impact of temperature increase on productivity
Percentage change in GDP by country in 2030
Current Policies scenario

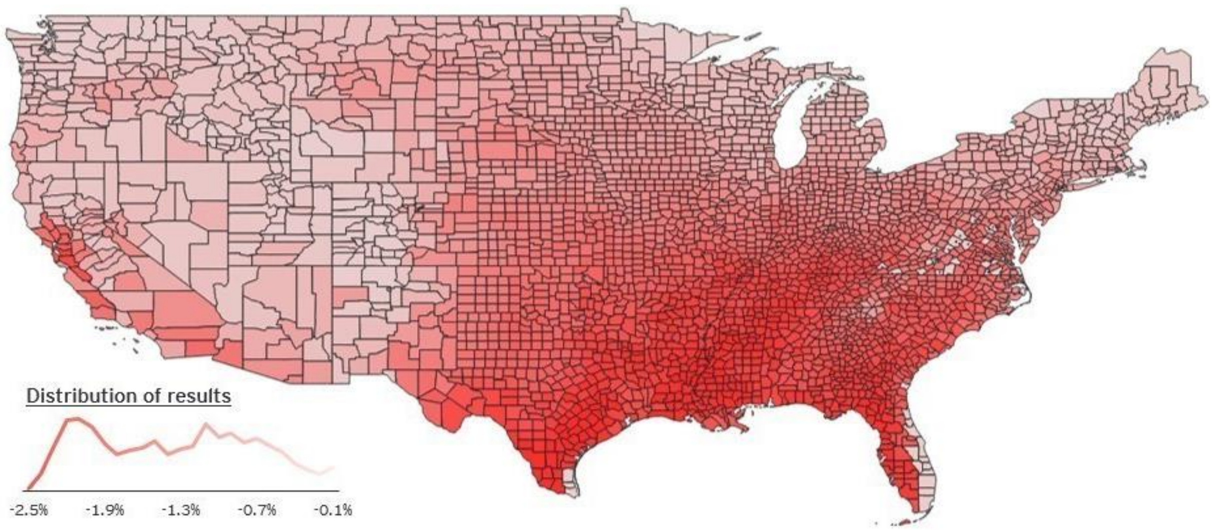


Source: NGFS; EY analysis.

<u>Subnational detail</u>

Like the policy transition risk, understanding subnational impacts is crucial for businesses, policymakers and stakeholders to understand the potential impacts of climate change. Figure 5 displays the percentage change in the level of GDP in the United States resulting from the impact of temperature increase on productivity in 2030 in the Current Policies scenario. As shown in the figure, the national average masks significant variation across the country. The most significant impacts are concentrated in the southeastern United States.

Figure 5: Physical risk — impact of temperature increase on productivity
Percentage change in GDP in the United States in 2030
Current Policies



Source: NGFS; EY analysis.

Other physical risks

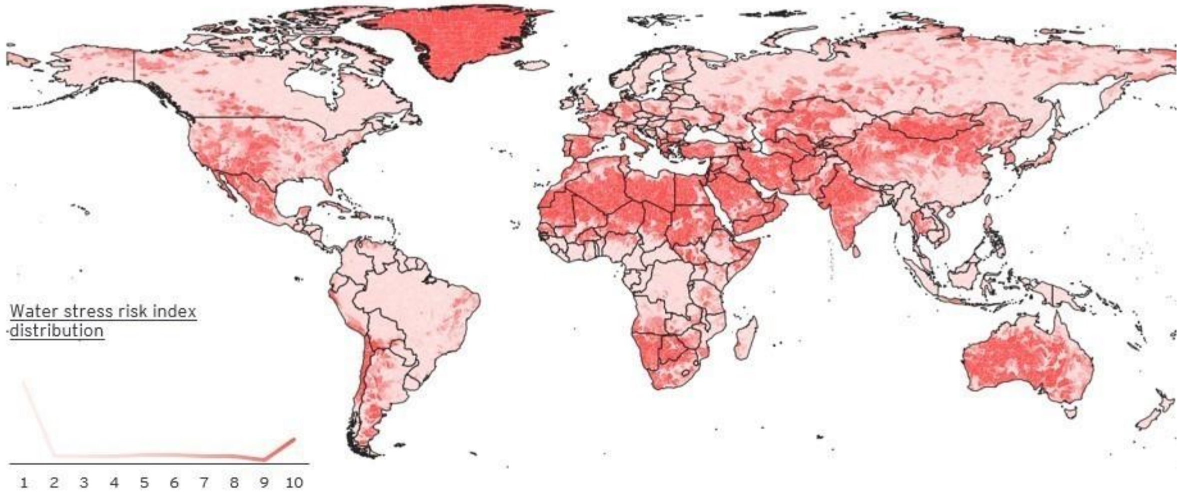
There are many other physical risk considerations beyond the impact of temperature increase on productivity. Figures 5 and 6, displayed above, examine productivity impacts related to changes in temperature, but do not consider effects of non-market and extreme weather events. This includes social dynamics, sea level rise and other events, which could directly or indirectly impact the global economy.[22] Other important physical risk indicators, as analyzed in more detail below, include:

1. Water stress
2. River flooding
3. Coastal flooding
4. Hurricanes
5. Fires
6. Heat waves
7. Cold waves

Water stress

The water stress risk index is based on the current ratio of total water withdrawals to the available renewable surface and groundwater supplies. That is, a higher ratio indicates more competition over water sources among users.[23] The index includes values from 1 to 10, where 10 (dark red) reflects a higher water stress risk and 1 (light red) reflects a lower water stress risk. The global average baseline water stress index is 1.03. As seen in Figure 6, however, the global average masks significant variation across the globe. Consider the five major global cities: Hong Kong, London, Paris, New York and Sydney. Sydney has the highest water stress risk index ranking (1.03), followed by Paris (1.02), New York (1.02), London (1.02) and Hong Kong (1.00). The largest concentration of high risk can be seen in North Africa, as shown in Figure 6.

Figure 6: Water stress risk index

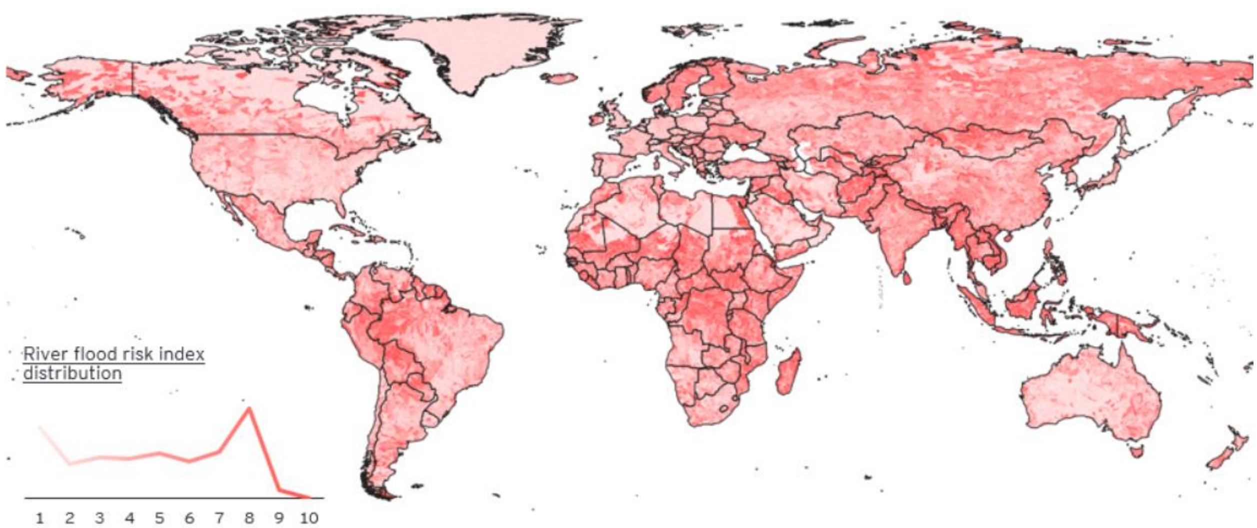


Source: WRI; EY analysis.

River floods

The river flood risk index is based on the current percentage of the population expected to be affected by river flooding in an average year, accounting for existing flood-protection standards.[24] A higher number for river flood indicates a higher percentage of people affected by river flooding. The risk index includes values from 1 to 10, where 10 (dark red) reflects a higher river flood risk and 1 (light red) reflects a lower river flood risk. The global average riverine flood risk index is 1.1. Looking at the five major global cities, Sydney has the highest risk index value at 1.17, followed by Hong Kong (1.09), Paris (1.03), London (1.03) and New York (1.01). The largest concentrations of high river-flood risk can be seen in sub-Saharan Africa and parts of Latin America.

Figure 7: River flood risk index

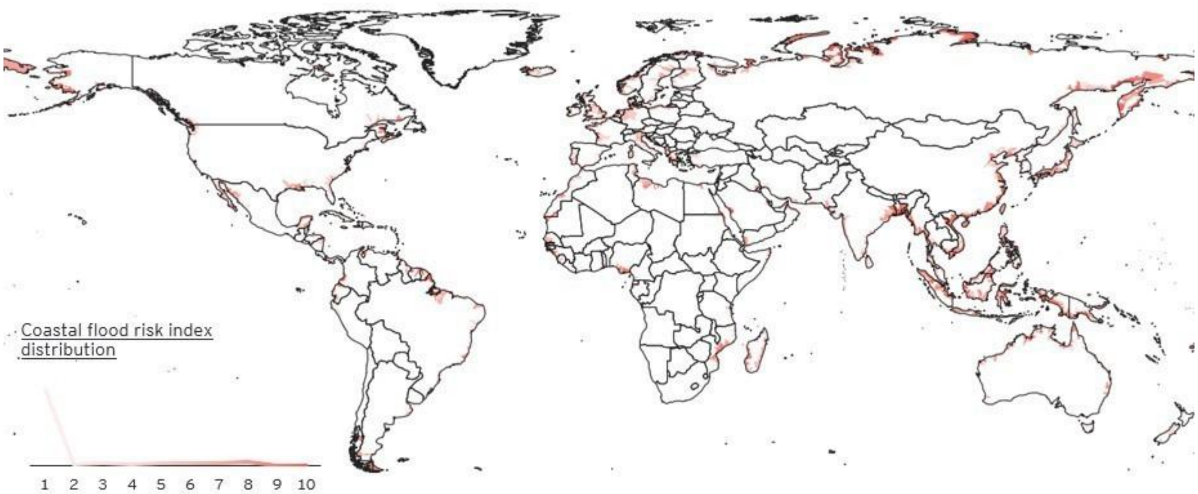


Source: WRI; EY analysis.

Coastal floods

The coastal flood risk index is based on the current percentage of the population expected to be affected by coastal flooding in an average year, accounting for existing flood-protection standards.[25] A higher value indicates a higher percentage of people affected by coastal flooding. The risk index ranges from 1 to 10, where 10 (dark red) reflects a higher coastal flood risk and 1 (light red) reflects a lower coastal flood risk. The global average flood risk is 1.01. Both Hong Kong and London have a coastal flood risk index value at or above the world average, at 1.06 and 1.01, respectively. New York, Paris and Sydney have a coastal flood risk index of 1.0.

Figure 8: Coastal flood risk index

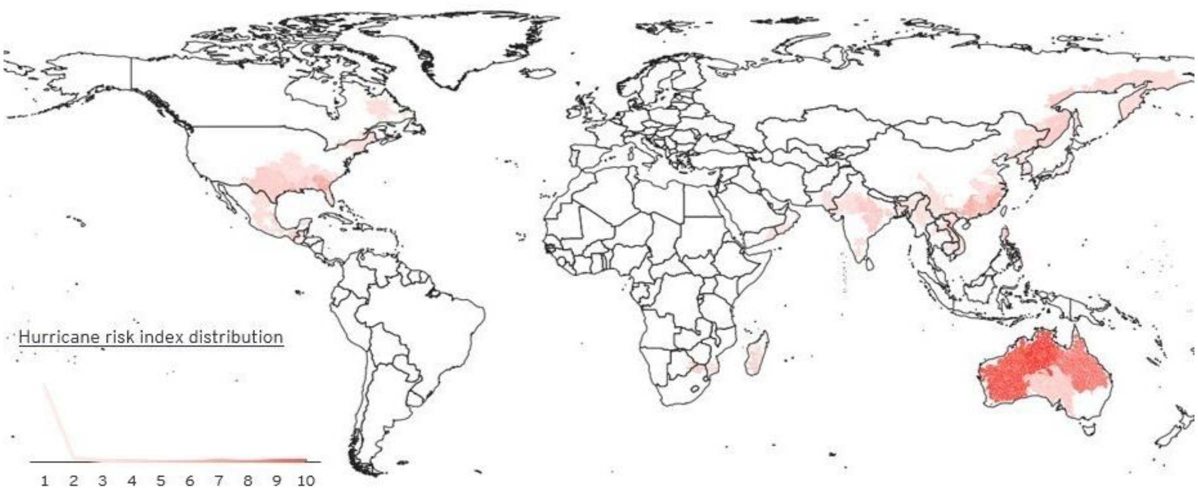


Source: WRI; EY analysis.

Hurricane risk index

The hurricane risk index is based on the recent number of hurricanes per specified geographic area.[26] The hurricane risk index ranges from 1 to 10, where 10 is a higher hurricane risk, shown in dark red in Figure 9 below. The global average hurricane risk index is 1.34. Of the five major global cities, Hong Kong has the highest hurricane risk index score (3.48), followed by New York (1.19). Sydney, Paris and Sydney have a hurricane risk index score of 1. The areas with the highest risk of hurricanes include Australia, the United States, India and China Mainland.

Figure 9: Hurricane risk index

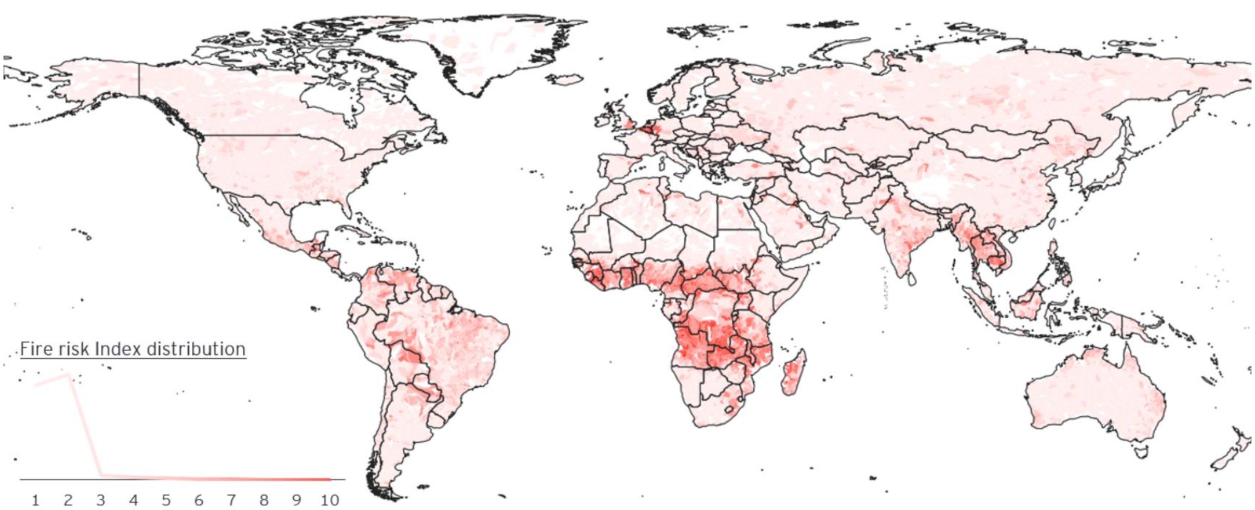


Source: NOAA; EY analysis.

Fire risk index

The fire risk index is based on the recent intensity-adjusted number of fires per specified geographic area.[27] The global fire risk average index is 1.41. Of the five major global cities, London and Hong Kong have the highest fire indices at 2.47 and 1.23, respectively, followed by New York (1.06), Paris (1.03) and Sydney (1.00). Areas with the highest risk of fires are concentrated within the middle part of sub-Saharan Africa.

Figure 10: Fire risk index

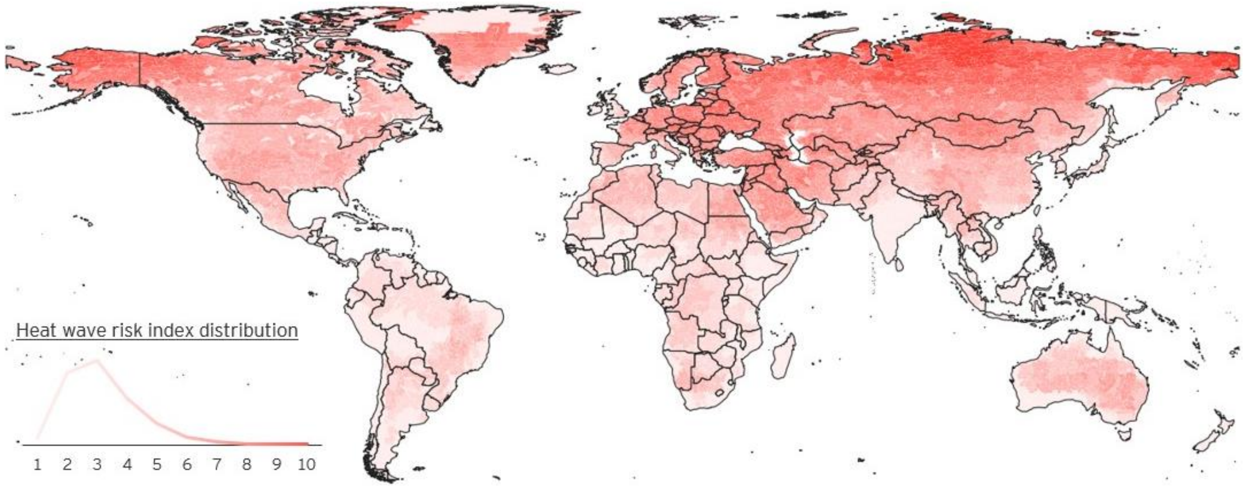


Source: NASA; EY analysis.

Heat wave risk index

The heat wave risk index is based on the number of recent positive temperature anomalies (i.e., temperature observed being hotter than reference value) per specified geographic area.[28] The risk index ranges from 1 to 10, where 10 (dark red) reflects a higher heat wave risk and 1 (light red) reflects a lower heat wave risk. The global average heat wave index is 3.25. Of the five major global cities, Paris has the highest heat wave index at 4.44, followed by New York (2.93), London (2.78), Sydney (2.71) and Hong Kong (2.35).

Figure 11: Heat wave risk index

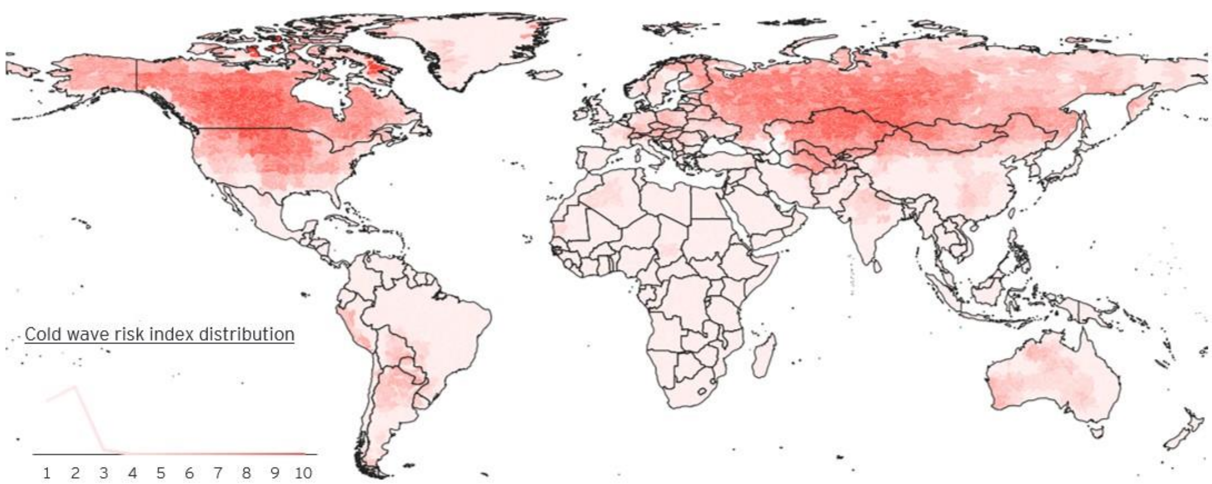


Source: NOAA; EY analysis.

Cold wave risk index

The cold wave risk index is based on the number of recent negative temperature anomalies (i.e., temperature observed being cooler than reference value) per specified geographic area.[29] The risk index ranges from 1 to 10, where 10 (dark red) reflects a higher cold wave risk and 1 (light red) reflects a lower cold wave risk. The global average cold wave index is 1.42. Of the five major global cities, Paris has the highest risk at 1.29, followed by New York (1.27), Hong Kong (1.09), and London and Sydney (1.06).

Figure 12: Cold wave risk index



Source: NOAA; EY analysis.

VI. Conclusion

It is crucial for businesses, policymakers and other stakeholders to understand the significant economic risks associated with climate change. The carbon emission reduction goals and policies being considered or implemented by jurisdictions around the world could have significant and diverse impacts across markets and communities. However, physical climate change risks have already negatively impacted communities across the globe. If climate change is not addressed, these physical climate impacts will continue to escalate, in frequency and severity. Understanding the relevant risks will help businesses, policymakers and other stakeholders to engage with consumers, employees, investors and citizens to develop and implement the most effective policy approaches to address these risks. It will also help prepare all stakeholders for a world with rapidly developing GHG mitigation policies and environmental challenges.

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Endnotes

[1]United Nations Framework Convention on Climate Change, *The Paris Agreement*, (accessed via https://unfccc.int, 4 September 2021).
[2] *Climate Change 2021: The Physical Science Basis Summary for Policy Makers*. IPCC, 2021.
[3] *Climate Change 2021: The Physical Science Basis Summary for Policy Makers*. IPCC, 2021.
[4] "Sustainable Development Goals," *United Nations website,* https://sustainabledevelopment.un.org/topics/sustainabledevelopmentgoals, accessed 5 September 2021.
[5] "Putting a Price on Carbon with an ETS," *World Bank* website, https://www.worldbank.org/content/dam/Worldbank/document/Climate/background-note_ets.pdf, accessed 4 September 2021.
[6] "Putting a Price on Carbon with an ETS," *World Bank* website, https://www.worldbank.org/content/dam/Worldbank/document/Climate/background-note_ets.pdf, accessed 4 September 2021.
[7] *Climate Change 2021: The Physical Science Basis Summary for Policy Makers*. IPCC, 2021.
[8] United Nations Framework Convention on Climate Change, *The Paris Agreement*, (accessed via https://unfccc.int, 4 September 2021).
[9] See body of document for scenario definitions.
[10] Generally, NGFS results presented are the average from the GCAM, MESSAGEix-GLOBIOM and REMIND-MAgPIE simulations. A notable exception to this is the productivity impacts from temperature increases, which are only available from REMIND-MAgPIE.
[11] "Origin and Purpose", *NGFS website*, https://www.ngfs.net/en/about-us/membership, accessed 23 September2021
[12] "Membership", *NGFS website*, accessed 23 September2021.
[13] The transition pathways for the NGFS scenarios were generated by the following IAMs: GCAM (Global Change Assessment Model), MESSAGEix-GLOBIOM (Model for Energy Supply Strategy Alternatives and their General Environmental Impact & Global Recursive Dynamic Partial Equilibrium Model), and REMIND-MAgPIE (Regional Model of Investments and Development & Regional Model of Investments and Development). The NGFS also used a short-term macroeconomic model (NiGEM), which is not discussed in this report.

GCAM is a model based on the interaction between the energy, water, agriculture, land use, and economy systems. Within GCAM agents use information from relevant data to make decisions about allocation of resources, a solution for market-equilibrium is found and agents continue making decisions in each period as they gain new information. The effects of climate change are included in the market-equilibrium solution.

MESSAGEix-GLOBIOM, is made up of MESSAGEix (Model for Energy Supply Strategy Alternatives and their General Environmental Impact), which is an energy model, and GLOBIOM (Global Recursive Dynamic Partial Equilibrium Model), which is a land use model. The MESSAGEix optimizes land use data from GLOBIOM and feeds it into MAGIC (Model for the Assessment of Greenhouse Gas Induced Climate Change), which provides an estimate for projected climate implications.

REMIND-MAgPIE, is made up of the REMIND (Regional Model of Investments and Development) model, which optimizes energy and economic investments in the economy to maximize welfare, and MAgPIE (Model of Agricultural Production and its Impacts on the Environment), which is a land use and agricultural emissions model. REMIND-MAgPIE runs a subset of scenarios with implementation of internalized physical risk damage, and has dynamics within and between water, air pollution, land use, energy, health, economy and climate systems.

The models mainly divide the world into 12 regions, including four jurisdictions and eight aggregated regions. The four jurisdictions are China, India, Japan, and the United States of America. The integrated regions are the European Union (EU), Latin America and the Caribbean (LAM), Middle East/North Africa/Central Asia (MEA), Non-EU Europe (Non-EU), other Asia, Countries from the Reforming Economies of the Former Soviet Union (REF), Sub-Saharan Africa (SSA) and Canada/Australia/New Zealand (CAZ).
[14] https://www.ngfs.net/sites/default/files/medias/documents/820184_ngfs_scenarios_final_version_v6.pdf
[15] Generally, capital taxes have a more negative economic impact than personal income taxes and personal income taxes have a more negative economic impact than consumption taxes. See, for example, Arnold, J., et. Al., Tax Policy for Economic Recovery and Growth, *The Economic Journal*, February 2011. Additionally, even within these categories of taxes some have a more negative economic impact than others. See, for example, US Treasury Department, "US Treasury Conference on Business Taxation and Global Competitiveness," July 2007, which compares a variety of changes to capital taxation: tax depreciation rules, corporate income taxation, dividend and capital gains taxes and expansion of tax-free savings accounts. There are, of course, other policy considerations beyond the impact of a policy on the overall size of the economy (e.g., distributional considerations).
[16] See EY, *Carbon regulations vs. a carbon tax: A comparison of the macroeconomic impacts*, October 2018. https://amsresearch.org/wp-content/uploads/2018/10/AMS_EY-Report_Full-Report.pdf

[17] Specifically, the analysis modeled the permanent extension of expiring individual income tax provisions in the Tax Cuts and Jobs Act and permanent expensing of investment in equipment.

[18] All scenarios simulated an identical reduction in carbon emissions. Because the different uses of the revenue generated from a carbon tax differ in their impact on the economy, the exact carbon price differs across the various simulations. Additionally, these results are long-run results. The long-run represents when the economy reaches a new steady state.

[19] This was modeled in through alternative ways: (i) a national emissions rate for each electricity-generating unit (in CO2/MWh), (ii) a state-specific emissions rate for the state's overall electricity portfolio (in CO2/MWh), and (iii) state-specific mass-based limits (in CO2/year).

[20] For more information see EY, *Carbon regulations vs. a carbon tax: A comparison of the macroeconomic impacts*, October 2018. https://amsresearch.org/wp-content/uploads/2018/10/AMS_EY-Report_Full-Report.pdf

[21] These simulations used an EY macroeconomic model as a national model for the United States. Subnational estimates were produced by applying the national industry-level results to the industry composition of each county within the United States. This should be viewed as an illustrative, high-level analysis.

[22] Bertram C., Hilaire J, Kriegler E, Beck T, Bresch D, Clarke L, Cui R, Edmonds J, Charles M, Zhao A, Kropf C, Sauer I, Lejeune Q, Pfleiderer P, Min J, Piontek F, Rogelj J, Schleussner CF, Sferra, F, van Ruijven B, Yu S, Holland D, Liadze I, Hurst I. (2021) : *NGFS Climate Scenario Database: Technical Documentation V2.2*

[23] *Baseline water stress, Aqueduct Global Maps 3.0 Data*. The World Resource Institute (2019). https://www.wri.org/data/aqueduct-global-maps-30-data

[24] *Riverine flood risk, Aqueduct Global Maps 3.0 Data*. The World Resource Institute (2019). https://www.wri.org/data/aqueduct-global-maps-30-data

[25] *Coastal flood risk, Aqueduct Global Maps 3.0 Data*. The World Resource Institute (2019). https://www.wri.org/data/aqueduct-global-maps-30-data

[26] In particular, the index is based on the count of hurricanes/cyclones over the most recent 5-year period (2016-2020). *International Best Track Archive for Climate Stewardship (IBTrACS version 4)*. (n.d.). National Centers for Environnemental Information- NOAA. https://www.ncdc.noaa.gov/ibtracs/index.php?name=ib-v4-access

[27] In particular, the index is based on the count of fires adjusted as indicated by NASA's Visible Infrared Imaging Radiometer Suite (VIIRS) 375 m. The index sums thermal anomalies recorded by VIIRS brightness temperature I-4 indicator, which measures fires, over a five-year period from 2016-2020. The result is compound brightness temperature of the fire pixel measured in Kelvin per specified geographic area for the five years, and is then indexed to a range of 1–10. *VIIRS I-Band 375 m Active Fire Data*. (2021). NASA https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms/viirs-i-band-active-fire-data

[28] In particular, the number of heat waves over the most recent five-year period (2016-2020) are examined. Reference temperatures are based on a 30-year average of temperature data from NOAA: *NOAAglobaltemp*. National Centers for Environmental Information (NCEI). (2021, September 20). Retrieved September 23, 2021, from https://www.ncei.noaa.gov/products/land-based-station/noaa-global-temp.

[29] In particular, the number of cold waves over the most recent five-year period (2016-2020) are examined. Reference temperatures are based on a 30-year average of temperature data from NOAA: *NOAAglobaltemp*. National Centers for Environmental Information (NCEI). (2021, September 20). Retrieved September 23, 2021, from https://www.ncei.noaa.gov/products/land-based-station/noaa-global-temp.