Sustainability Insights | Research

Lost GDP: Potential Impacts Of Physical Climate Risks

Nov. 27, 2023

Physical risks linked to climate change may become an increasing source of supply-side shocks for the global economy, particularly if adaptation and resilience investments are not stepped up.

This research report explores an evolving topic relating to sustainability. It reflects research conducted by and contributions from S&P Global Ratings' sustainability research and sustainable finance teams as well as our credit rating analysts (where listed).

This report does not constitute a rating action

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This research aims to provide insights into the potential exposure and readiness of rated countries to different types of climate hazards. We use four climate scenarios to examine the potential exposure of 137 countries to economic losses caused by the physical impacts of climate change. We map the potential exposure of economic output and population to seven climate hazards, using average historical loss rates associated with these hazards. We also use sovereign economic and institutional assessments as a proxy to assess countries' readiness to adapt and recover from those events.

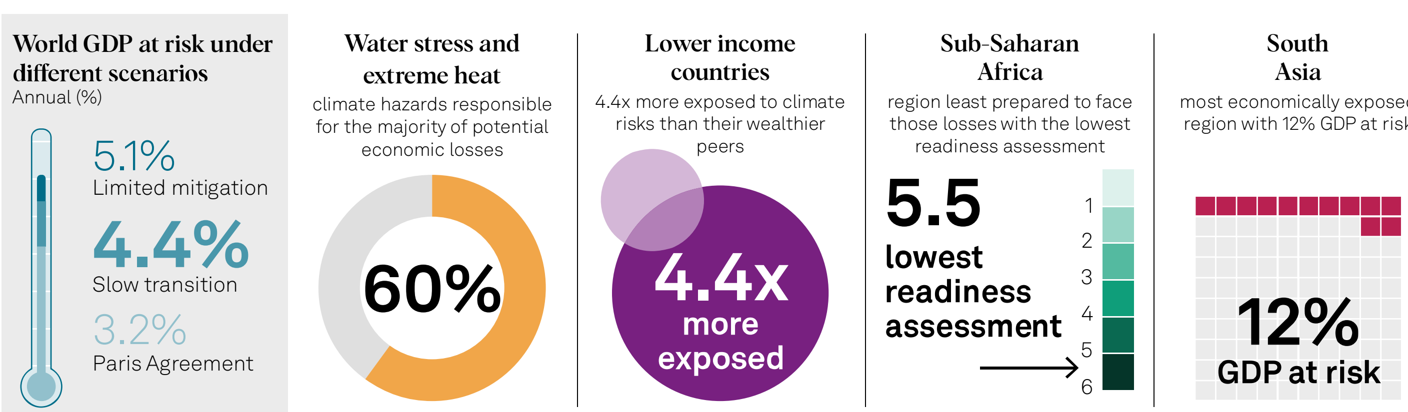
This research builds on (and is distinct from) our previous research "Weather Warning: Assessing Countries' Vulnerability To Economic Losses From Physical Climate Risks," published April 27, 2022. Here, we use the latest climate hazard modelling data, which focuses attention on exposure to hazards attributable to climate change, rather than hazards in a pre-climate-change state. We also made changes to metrics and to our definitions of each climate hazard.

Key Findings

- **By 2050, if global warming does not stay well below 2 degrees Celsius (2 C), up to 4.4% of the world's GDP could be lost annually, absent adaptation.** This will test countries' adaptation plans, particularly those of lower-income nations that are disproportionately exposed and less able to prevent permanent losses. The GDP at risk measure is based on a static view of the economy, assuming no adaptation and that all hazards occur in one year in all exposed places.
- **The rising likelihood of compound climate events adds to the challenges of climate analytics**. Understanding these non-linear dynamics appears crucial to assessing specific risks each country faces and may help policymakers pursue more-targeted policies.
- **The adaptation gap is widening, given slow progress on preparedness, and financing conditions are tightening**. Financing rising adaptation costs as the impacts of climate hazards worsen may become more difficult in an environment of higher interest rates, adding another hurdle to developing countries' adaptation implementation.

Consistent with its criteria, S&P Global Ratings incorporates the adverse physical effects of climate change--along with all other factors that could be relevant and material to creditworthiness--into its credit analysis. We do this when we believe such factors could materially influence the creditworthiness of a rated entity, or issue, and we have sufficient visibility on how those factors will evolve or manifest. However, the findings of this research are currently not part of our base case for sovereign ratings, given the uncertainties inherent in climate projections.

By the numbers: Economic impact of a slow transition scenario



Note: Lower income = Low and lower middle income, based on World Bank data.

Economic Losses From Physical Risks Are Rising

From 1992 to 2022, the growth trend of annual insured losses from natural disasters averaged 5%-7% per year, with more severe climatic events accounting for the majority of insured losses, according to Swiss Re. By 2030, if mitigation is not stepped up, the number of disasters could be 40% higher than in 2015, with 250 events per year, states the UN Office for Disaster Risk Reduction in a 2022 report.

Impacts will be heterogeneous. In previous research, S&P Global Ratings found that lower- and lower-middle income countries are most vulnerable, least ready to adapt, and require the greatest amounts of investment to build resilience to physical climate risks. Nearly half of the world's population will live in areas that are highly vulnerable to climate change by 2050 (double what it is today), further reinforcing the need for adaptation, as stated in in a 2022 report from the Intergovernmental Panel on Climate Change (IPCC).

Barriers to adaptation remain a challenge for those most vulnerable. According to a United Nations Environment Program (UNEP) report, published in 2023, the proportion of developing countries that have adopted at least one National Adaptation Plan, strategy, or policy has increased to over 80%, while the amount of international public finance flowing to those countries has decreased (by 15% in 2021 year on year). Most adaptation finance is also provided in the form of debt instruments (63% of all adaptation-specific finance consisted of loans between 2017 and 2021). What's more, disbursement ratios--that is, the amount of finance disbursed during a year as a percentage of the undisbursed balance at the beginning of that year--among those international public finance institutions have also declined over the past five years.

Adaptation and resilience investments also lag what's required. The adaptation finance gap is $194 billion-$366 billion per year, or 0.6%-1.0% of developing countries' GDP, as reported by UNEP (2023). With this in mind, adaptation will become as important as climate transition financing in terms of protecting wealth and lives over the next decades (see "Crunch Time: Can Adaptation Finance Protect Against The Worst Impacts From Physical Climate Risks," published Jan. 13, 2023).

Seven Climate Hazards To Assess Physical Risks

We use seven climate hazards in our scenario analysis (see the Appendix): extreme heat, fluvial flooding (severe river flooding), pluvial flooding (severe rainfall), sea-level rise (also called coastal flooding), water stress (where water withdrawals exceed renewable water supply), wildfires, and storms (cyclones, hurricanes, and typhoons).

We look at compound events (climate hazards occurring at the same time or consecutively) to uncover non-linear impacts. Using data on historical loss rates associated with these hazards, we estimate the potential economic impacts. This analysis contributes to understanding the distribution and scale of potential losses from physical climate risks globally.

Macroeconomic Dynamics Of Physical Climate Risks

All other things being equal, the increasing crystallization of physical climate risks gradually erode countries' productive capacity via weaker investment, lower productivity, higher mortality rates, and capital losses.

Climate change will increasingly disrupt economic activity, mainly through the supply side. Agriculture is relatively more exposed to extreme weather conditions due to its direct dependence on the climate. Acute physical climate risks manifest as more-sudden, negative supply-side shocks, which increase output volatility. Heat waves impair the productivity of people working outdoors, while water stress reduces agricultural and energy production. Long-term losses manifest through damage to capital and health, as well as lives lost (such as due to floods or storms; Hsiang and Jina 2014). Acute events can also affect demand via destruction of wealth, such as when physical assets--like homes--are destroyed and not covered by insurance (see "Climate change will heighten output volatility," Jan. 5, 2023).

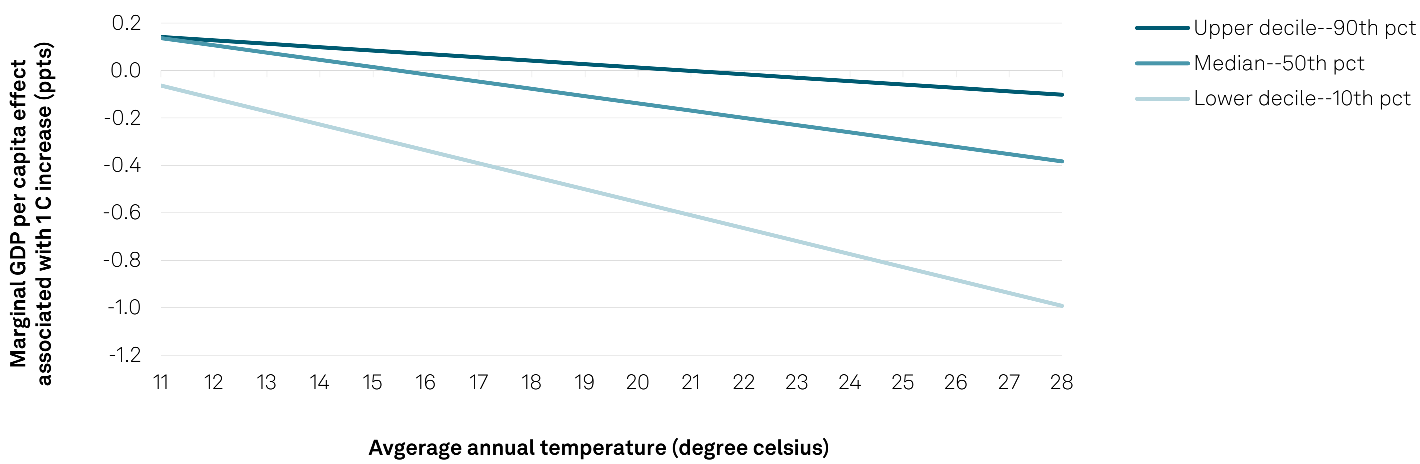
Non-linear impacts are likely. Historically, the relationship between GDP growth and temperature has been non-linear, implying that the marginal increase in temperature is more costly the higher the temperature starting point (see "Sustainability Insights: Is Climate Change Another Obstacle To Economic Development?," Jan. 16, 2023). In the future, climate change is likely to be non-linear once a set of tipping points are reached, but other non-linearities can arise from the interaction of climate hazards:

- First, climate hazards can compound one another, meaning they lead to greater impacts because they occur at the same time or consecutively. For example, droughts increase the likelihood that torrential rains shortly afterward result in floods.
- Second, they can compound the impact of previous economic weakness and amplify downturns. For example, the decline in GDP growth associated with temperature increases appears to be greater when GDP growth is already low (see chart 1 and Kiley, 2021). The amplification of impacts in this way was observed in Mexico when hurricanes compounded the effects of COVID-19 (see Dunz et al.; 2021).
- Third, they can trigger bigger system dynamics in the natural space or socioeconomic space, such as supply-chain disruptions, commodity price swings, migration, and/or conflict. A 2023 report from the International Monetary Fund (IMF) suggests climate change exacerbates both conflict intensity and internal displacement in fragile states.

Chart 1

A 1 C increase in temperature is likely to amplify downturns for weaker economies

GDP impact based on three GDP growth deciles



Note: Chart uses a quantile regression, where we cut our GDP per capita growth sample into deciles. We show the impact of temperature increases under different business cycle scenarios (growth decile). pct--Percentile. ppts--Percentage points.
Source: S&P Global Ratings ("Is Climate Change Another Obstacle To Economic Development?" Jan. 16, 2023).

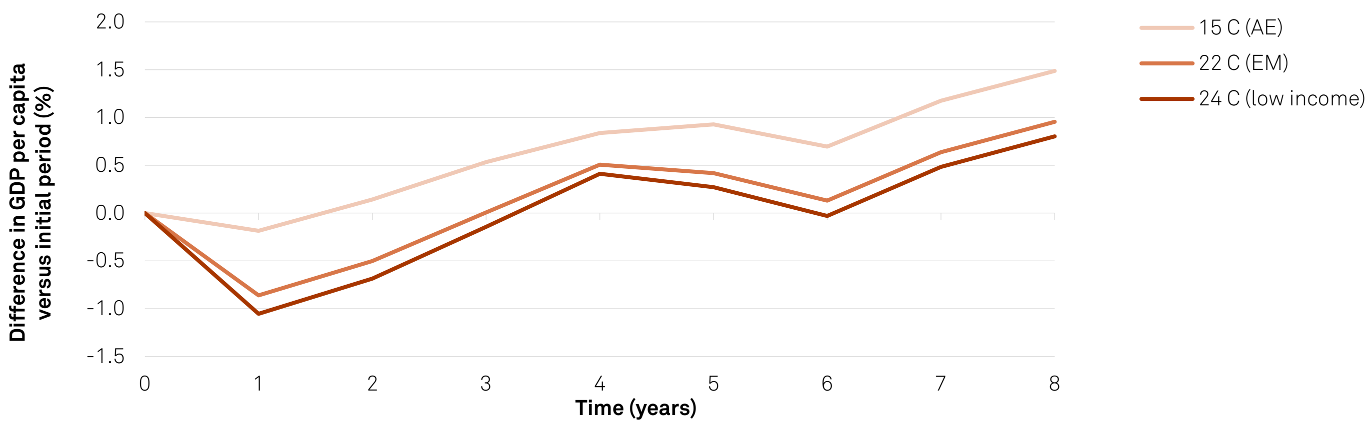
Countries' recovery from climate-related losses will differ due to economic and institutional disparity. The extent of long-term losses depends on how swiftly an economy recovers and how well it adapts to climate change in the future. Climate-related shocks are more likely to have a permanent impact in less developed economies, with readiness being one of the main factors explaining why some countries can cope with climate hazards, while others take longer to recover and face relative wealth losses (see charts 2 and 3):

- First, economies with fewer resources, tighter financing conditions, and lower insurance coverage take more time to get back on their feet. The costs of recovery can be very large, as we observed after floods in Pakistan in 2022 when the country's reconstruction needs were 1.6 times the national budget (according to the World Bank). In addition, the policy goal of development may not always prioritize dealing with climate risk, even though those two are interlinked, since other issues, such as alleviating poverty, may be more important.
- Second, building adaptation and resilience to climate hazards is harder where institutions are weak and economies have fewer resources. Policy uncertainty and macroeconomic volatility associated with institutional weakness constrain countries' ability to adapt to risks in general, while less flexible labor and product markets make it harder to prepare or relocate production after a crisis.

Chart 2

Temperature increases could have a permanent impact on relative GDP levels

GDP per capita response to a 1 C annual average temperature rise, by temperature starting point

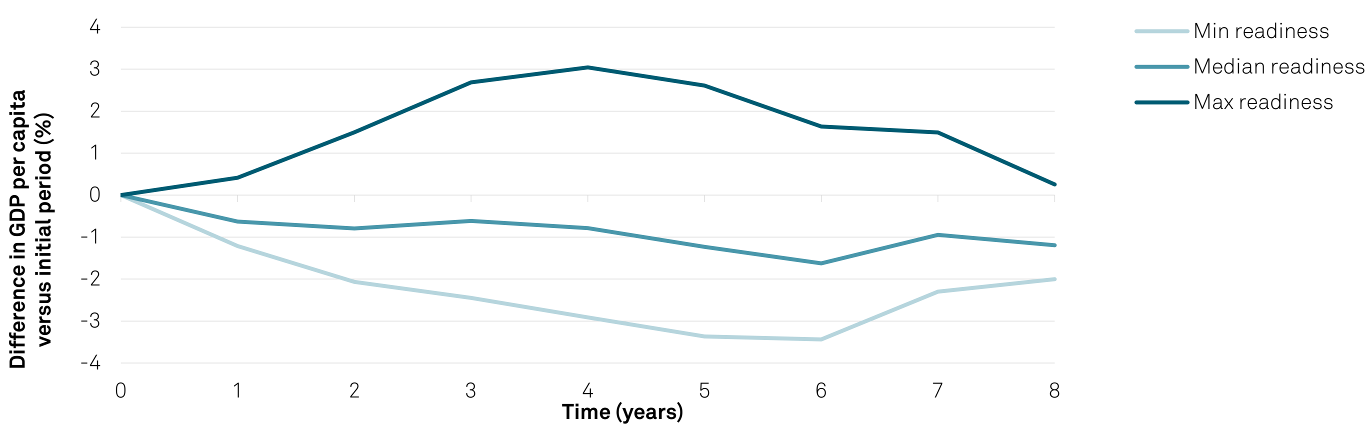


AE--Advanced economies. EM--Emerging markets. Source: S&P Global Ratings ("Is Climate Change Another Obstacle To Economic Development?" Jan. 16, 2023).

Chart 3

Countries with lower readiness display a long-lasting impact on GDP per capita

GDP per capita response over time to a 1 C annual average temperature rise from 24 C, by readiness



Sources: S&P Global Ratings ("Is Climate Change Another Obstacle To Economic Development?" Jan. 16, 2023), Notre Dame-Global Adaptation Index (ND-GAIN) Country Index.

Data And Approach To Assess Physical Climate Risks

To uncover some of the economic impacts of physical climate risks using the seven climate hazards, we applied four Shared Socioeconomic Pathways (SSPs; see box below). Given the lock-in effect of historical emissions, many of the physical risks of climate change will materialize irrespective of today's policy choices. Countries' current commitments (if met) align with a global temperature increase of between 2.4 C and 2.6 C by 2100--according to UNEP (2023)--close to that described by SSP2-4.5.

Shared Socioeconomic Pathways Defined

Shared Socioeconomic Pathways (SSPs) are a set of scenarios for projected greenhouse gas emissions and temperature changes. They incorporate broad changes in socioeconomic systems, including population growth, economic growth, resource availability, and technological developments:

- **SSP1-2.6 is a low emissions scenario** in which the world shifts gradually, but consistently, toward a more sustainable path. **This SSP aligns with the Paris Agreement's target** to limit the average increase in global temperature to well below 2 degrees Celsius (2 C) by the end of the century. The global temperature is projected to increase by 1.7 C (a likely range of 1.3 C-2.2 C) by 2050 or by 1.8 C (1.3 C-2.4 C) by the end of the century.
- **SSP2-4.5 is a moderate emissions scenario**, consistent with a future with relatively ambitious emissions reductions but where social, economic, and technological trends don't deviate significantly from historical patterns. This scenario is close to countries' **current pledges** but falls short of the Paris Agreement's aim of limiting the global temperature rise to well below 2 C, with a projected increase of 2.0 C (1.6 C-2.5 C) by 2050 or 2.7 C (2.1 C-3.5 C) by the end of the century.
- **SSP3-7.0 is a moderate-to-high emissions scenario - akin to a slow transition**, in which countries increasingly focus on domestic or regional issues, with slower economic development and lower population growth. A low international priority for addressing environmental concerns leads to rapid environmental degradation in some regions. This SSP projects a global temperature increase of 2.1 C (1.7 C-2.6 C) by 2050 or 3.6 C (2.8 C-4.6 C) by the end of the century.
- **SSP5-8.5 is a high emissions (limited mitigation) scenario**, in which the world places increasing faith in competitive markets, innovation, and participatory societies to produce rapid technological progress and development of human capital as a path to sustainable development. This SSP projects the global temperature increase at 2.4 C (1.9 C-3.0 C) by 2050 or 4.4 C (3.3 C-5.7 C) by the end of the century.

Source: Based on the IPCC's Sixth Assessment Report; AR6.

We chose to use SSP3-7.0 (a slow transition scenario) in both 2030 and 2050 given this lock-in effect and inherent challenges and uncertainties associated with long-term projections**.** The other SSPs and timepoints describe a broader range of possible outcomes, given the uncertainty. For example, SSP1-2.6 is a Paris Agreement-aligned scenario (limiting warning to 2 C above preindustrial levels) and SSP5-8.5 is a limited mitigation scenario.

We focus on the 137 countries we rate globally. We look at the impact on physical and human capital, and the potential implications for GDP, both at a country and regional level (see chart 4). We use three metrics to assess the economic impacts of physical climate risks.

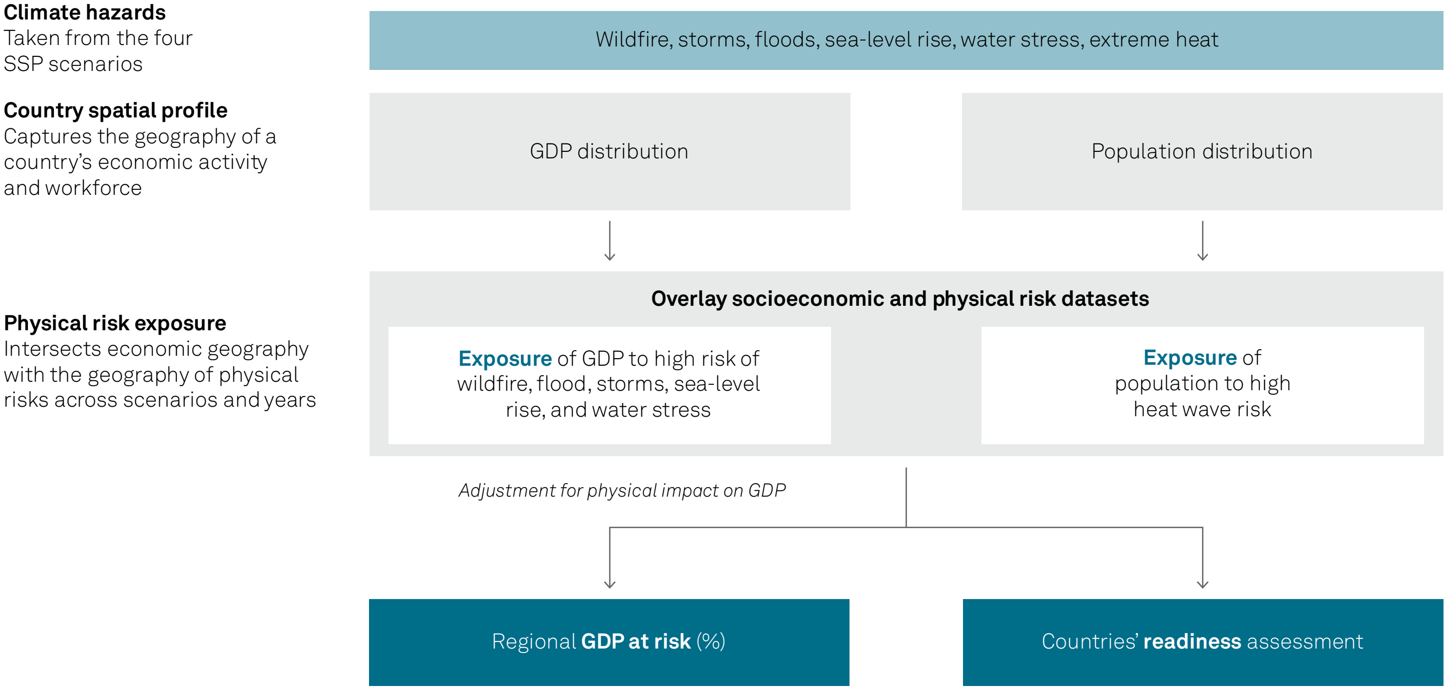
- **Exposure:** This metric quantifies the share of GDP or population likely to be affected by climate hazards.

- **GDP at risk:** The share of GDP that could be lost annually due to exposure to physical climate risks. This metric is based on a static view of the economy, so it doesn't account for adaptation to climate risk, changes in the economy's geography and structure, or any other growth dynamics. It also assumes all hazards occur every year.
- **Readiness:** This provides a relative picture of countries' ability to avoid and respond to some of these losses based on their economic and institutional strength. Readiness is on a scale of 1 to 6, where 6 indicates the lowest capacity to adapt and cope with the physical impacts of climate change.

Details of the data, approach, and limitations to our analysis are in the Appendix.

Chart 4

Approach for assessing countries' vulnerability to physical climate risks



Note: Storms includes hurricanes, typhoons, and tropical cyclones. Floods include river, sea-level rise, and pluvial floods.
Source: S&P Global Ratings 2023.

Climate Hazards Are Adding To Economic Risks

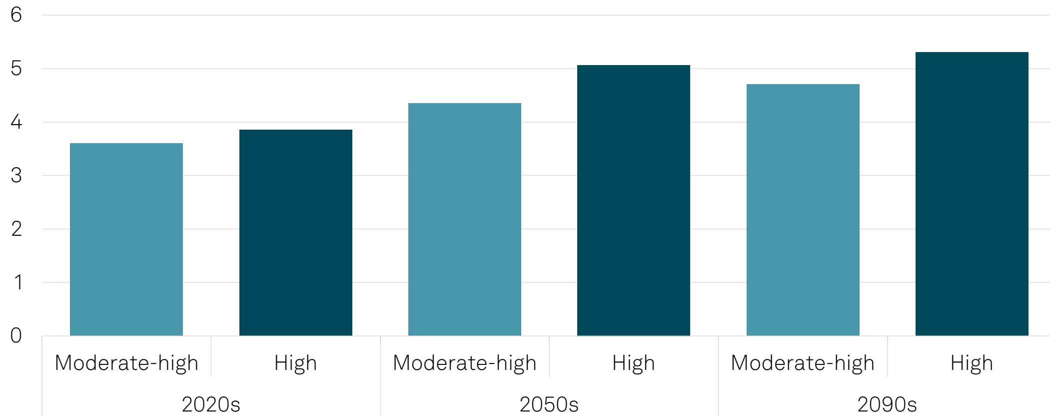
Physical risks from climate change are increasing and their economic and financial impacts are likely to rise with time, particularly if mitigation and adaptation efforts are not accelerated.

By 2050, if global warming does not stay well below 2 C, up to 4.4% of the world's GDP could be lost annually, absent adaptation. This is at least one-third greater than in the Paris Agreement's scenario (SSP1-2.6), where we find that 3.2% of global GDP may be at risk annually. GDP at risk rises to 5.1% under a limited-mitigation scenario, where emissions are high (SSP5-8.5) (see chart 5). For context, the Network for Greening the Financial System (NGFS; 2023a) estimates the cumulative costs of acute physical climate risks (heat waves, river floods, cyclones, and droughts) add up to 8% of world GDP by 2050 under its current policies scenario--equivalent to a temperature rise of about 3 C or higher by 2100. This is the closest scenario to the slow transition scenario (SSP3-7.0).

Chart 5

In slow mitigation scenarios, economies could see losses rise to 4.4%-5.1% of GDP by 2050

Percentage of world GDP at risk annually under SSP3-7.0 and SSP5-8.5 (%)



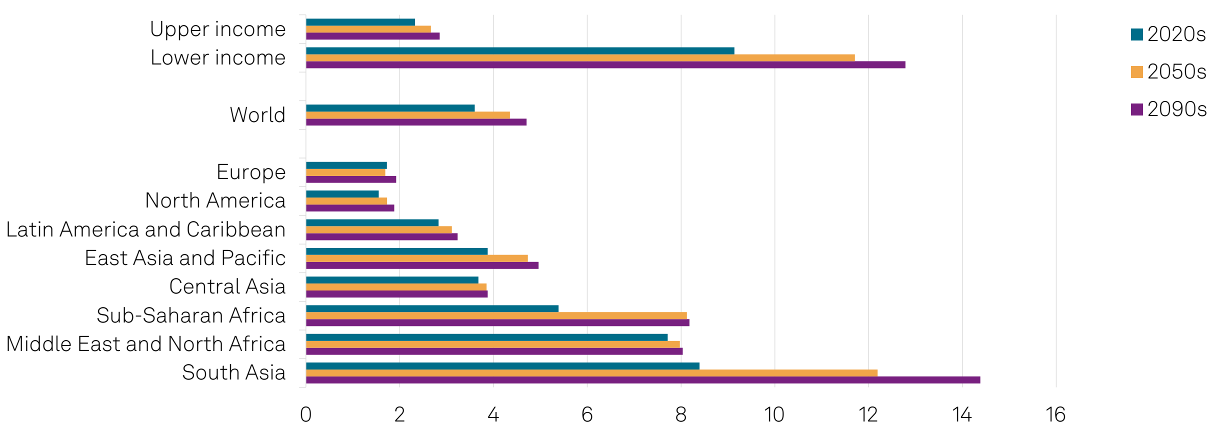
Note: GDP at risk represents the share of GDP that could be lost annually due to high exposure to physical climate risks, in the absence of adaptation to climate risk, without accounting for changes in the economic geography and structure and assuming all hazards occur every year. Moderate-high emissions scenario (SSP3-7.0). High emissions scenario (SSP5-8.5). Sources: S&P Global Ratings, S&P Global Sustainable1 (2023).

Exposure to the most adverse risks resulting from climate change is heterogenous across regions and income groups. South Asia faces 3 times more potential economic losses than the world average, with around 12% GDP at risk annually by 2050 (see chart 6) under a slow transition scenario (SSP3-7.0), absent adaptation. This region is followed by Sub-Saharan Africa, and the Middle East, and North Africa (MENA), each with 8% of GDP at risk. Europe and North America appear less exposed with around 2% GDP at risk. These geographic specificities are also reflected in country income groups. Lower- and lower-middle income countries already face higher average temperatures and more climate extremes than their upper- and upper-middle income peers. They are also set to face a larger share of damage related to physical climate risk, at about 12% of GDP at risk annually--4.4 times greater than their wealthier peers. Note that the regional results are likely to mask changes within countries.

Chart 6

South Asia faces about three times potential losses than the global average in 2050

Percentage of GDP at risk annually by region and income group under a slow transition scenario (SSP3-7.0), absent adaptation (%)



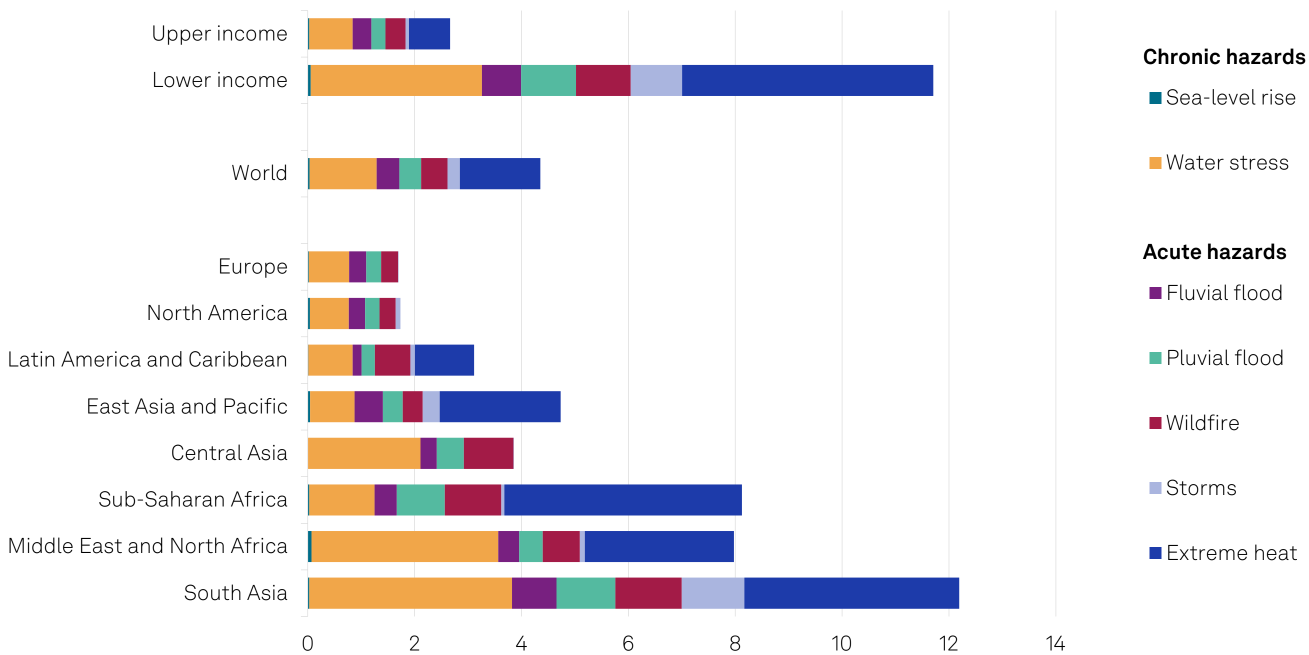
Note: Upper income = Upper middle and high income; Lower income = Low and lower middle income, based on World Bank data. GDP at risk represents the share of GDP that could be lost annually due to high exposure to physical climate risks, in the absence of adaptation to climate risk, without accounting for changes in the economic geography and structure and assuming all hazards occur every year. SSP3-7.0--Moderate-to-high emissions scenario. Sources: S&P Global Ratings, S&P Global Sustainable1 (2023).

Adapting and building resilience to the physical impacts of climate change remain highly context and location specific, influenced by countries' economic geography. This means investment needs are different in terms of size but so too are hazards (see chart 7). For example, storms are typically more prominent in South Asia, East Asia and Pacific, and the Caribbean than in land-locked nations in Central Asia, MENA, and Sub-Saharan Africa (see chart 8). This partly reflects existing conditions, with island nations such as the Philippines, Jamaica, or Japan already facing 100% of GDP exposure to storms compared to just 40% GDP exposure in the U.S. and only about 1% in Europe (except for Portugal and Gibraltar) in the 2050s. In the same vein, economic losses due to water stress--a chronic risk that materializes slowly over time--is considerably lower in Sub-Saharan Africa than in MENA since the location most at risk, the Sahara Desert, has not developed as an important economic hub.

Chart 7

Chronic risks dominate potential losses in Asia-Pacific and MENA

Annual GDP at risk by 2050 by climate hazard and region, under a slow transition scenario (SSP3-7.0) absent adaptation (%)

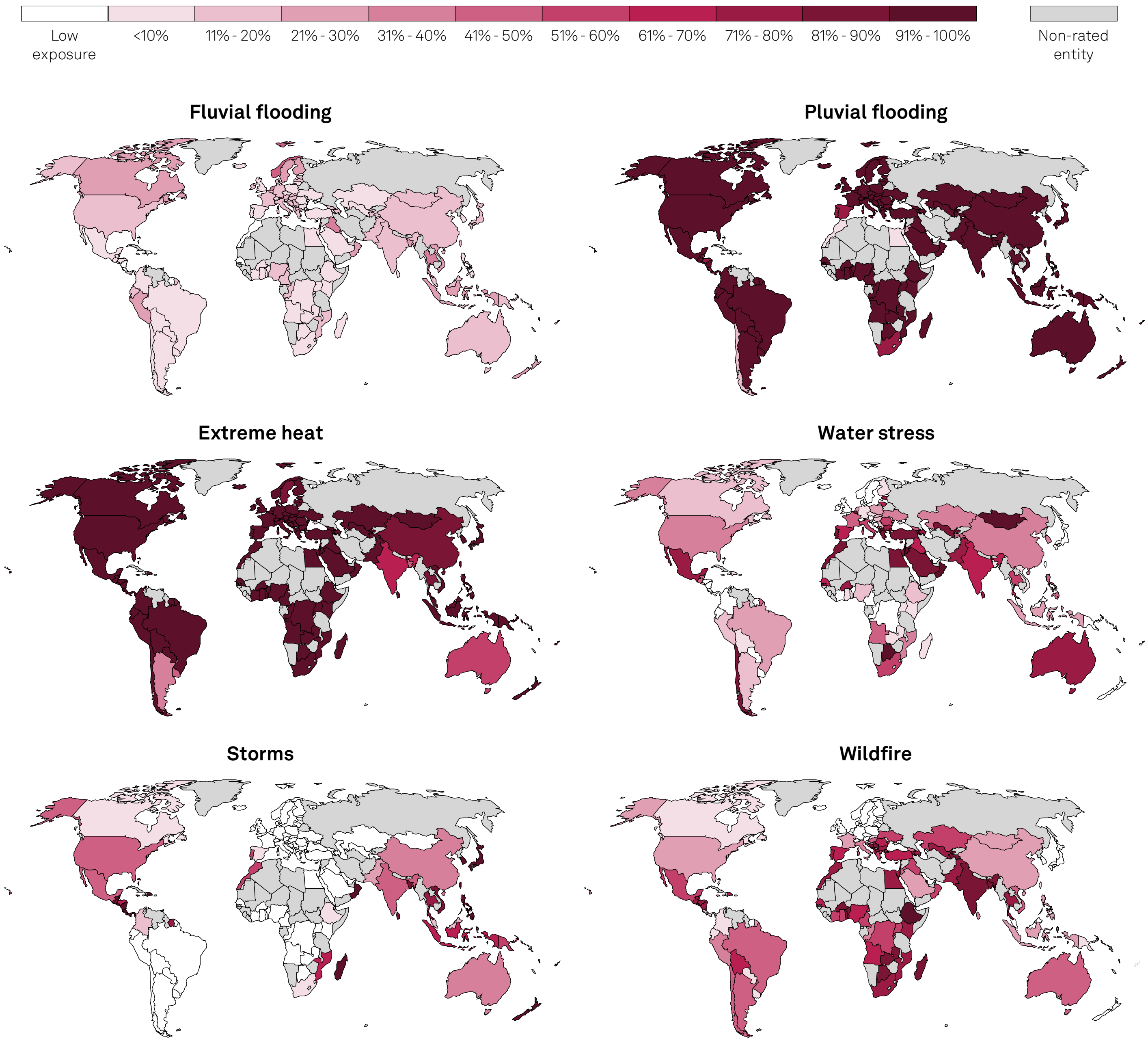


Note: Upper income = Upper middle and high income; Lower income = Low and lower middle income, based on World Bank data. GDP at risk represents the share of GDP that could be lost annually due to high exposure to physical climate risks, in the absence of adaptation to climate risk, without accounting for changes in the economic geography and structure and assuming all hazards occur every year. SSP3-7.0--Moderate-to-high emissions scenario. Sources: S&P Global Ratings, S&P Global Sustainable1 (2023).

Chart 8

Impacts from climate hazards will be heterogeneous

Annual GDP exposure by 2050, by climate hazard and region, under a slow transition scenario (SSP3-7.0) absent adaptation



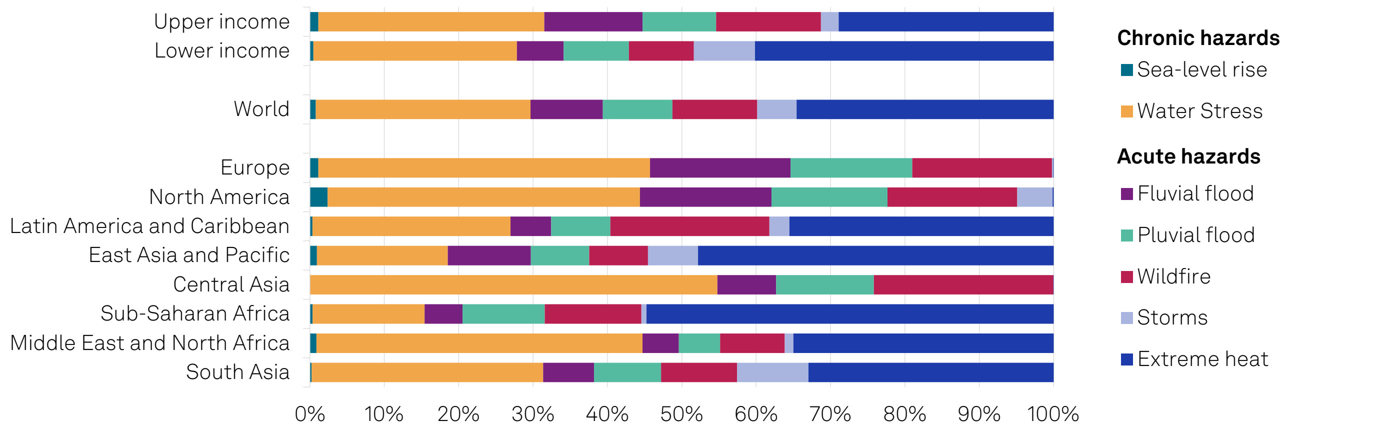
Note: Sea -level rise not shown due to coarseness of data when viewed at global scale. Exposure metric quantifies the % share of GDP exposure to each hazard, except extreme heat, which uses % population exposure. SSP3-7.0--Moderate-to-high emissions scenario. Sources: S&P Global Ratings, S&P Global Sustainable1 (2023).

Water stress and extreme heat events could represent more than 60% of potential economic losses associated with physical climate risk by 2050 under a slow transition scenario, absent adaptation. Other hazards--such as pluvial flooding, fluvial flooding, and wildfire--each contribute between 10% and 15% to losses (see chart 9).

Chart 9

Water stress and extreme heat cause the most physical-risk-related economic losses globally

Climate hazards' contribution to regional GDP at risk under a slow transition scenario (SSP3-7.0) in 2050, absent adaptation



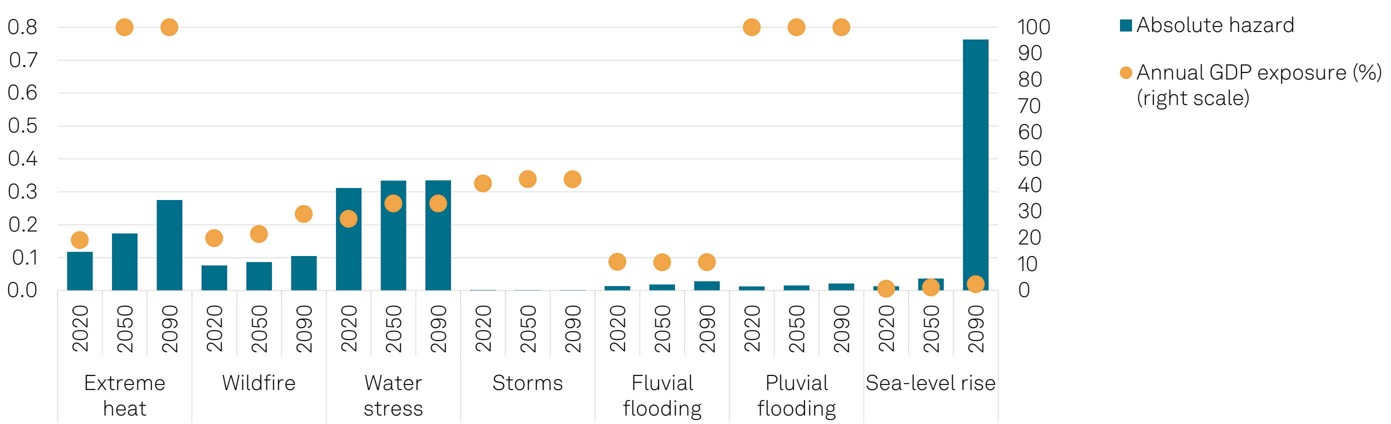
Note: Upper income = Upper middle and high income; Lower income = Low and lower middle income, based on World Bank data. GDP at risk represents the share of GDP that could be lost annually due to high exposure to physical climate risks, absent adaptation to climate risk, excl. changes in the economic geography and structure, and assuming all hazards occur every year. SSP3-7.0--Moderate-to-high emissions scenario. Sources: S&P Global Ratings, S&P Global Sustainable1 (2023).

Some further increases in impacts from climate hazards are not captured by exposure and GDP at risk metrics. Data that describes the absolute change in different climate metrics against historical trends reveals an increase in the tail of hazards' distribution as warming gains pace. This is not captured entirely by the GDP exposure metric. For example, in the U.S., the frequency of extreme heat events is projected to increase until the 2090s, but the exposure threshold (defined in table A2 in the Appendix) is already reached by 2050 (that is, 100% of GDP is exposed by this timepoint; see chart 10). Similarly, absolute hazard data highlights that some hazard frequencies increase more significantly than others, in particular for pluvial, fluvial, and sea-level rise. This suggests that our threshold definitions may understate the change in hazard impact over time, particularly post mid-century.

Chart 10

Pluvial flooding is already an issue for the U.S., with extreme heat set to worsen in 2050

Absolute hazard estimates for the seven climate hazards under a slow transition scenario (SSP3-7.0), absent adaptation



Note: Absolute hazard (columns, left scale) describes the absolute change in different climate metrics against historical trends. For example, for pluvial flood, the projected frequency of the historical 1 in 100-year flood depth (the baseline is 0.01 and thresholds defined in table A2 are used to identify high exposure to each climate hazard). The exposure metric quantifies the share of GDP or population likely to be affected by climate hazards. SSP3-7.0--Moderate-to-high emissions scenario. Sources: S&P Global Ratings, S&P Global Sustainable1 (2023).

The GDP at risk measure remains a static view of the economy, which doesn't necessarily capture future realized losses. This is because it assumes no change in economic geography, no adaptation, and that all hazards occur in one year in all exposed places. For example, South Asian countries--the most exposed to losses from climate hazards according to our analysis--have incurred lower losses to date than our GDP at risk metric suggests. Average losses in 2019 accounted for 3.1% of GDP in South Asia, according to the UN Economic and Social Commission for Asia and the Pacific; this corresponds to one-quarter of our risk metric of 12.2% of GDP at risk in 2050 under SSP3-7.0.

More Compound Events Point To Non-Linear Outcomes

As the climate becomes more extreme, the frequency of climate hazards is also more likely to increase simultaneously. The co-occurrence of events (or compound extremes) is already showing up in historical data. A recent example is the 2022 floods in Pakistan, which submerged one-third of the country and were caused by a combination of heavier-than-usual monsoon rains and a severe heat wave.

Specific climate hazard pairs have become more likely. This is according to the findings of Ridder et al. (2020) when looking at the joint occurrence of climate hazards between 1980 and 2014. The authors found that these pairs include but are not limited to:

- **Water stress and extreme heat**--These compound events may contribute to depleted water resources, increased energy demand, disruption to agricultural production, and a greater risk of wildfires;
- **Storms and flooding (pluvial/fluvial/sea-level rise)**--Storms (and associated high winds) and flooding can damage and disrupt infrastructure systems, particularly in low-lying coastal areas; and
- **Wildfire and extreme heat**--Higher average and extreme temperatures during wildfire events can contribute to sustained wildfire weather conditions, owing to low soil moisture content and low humidity.

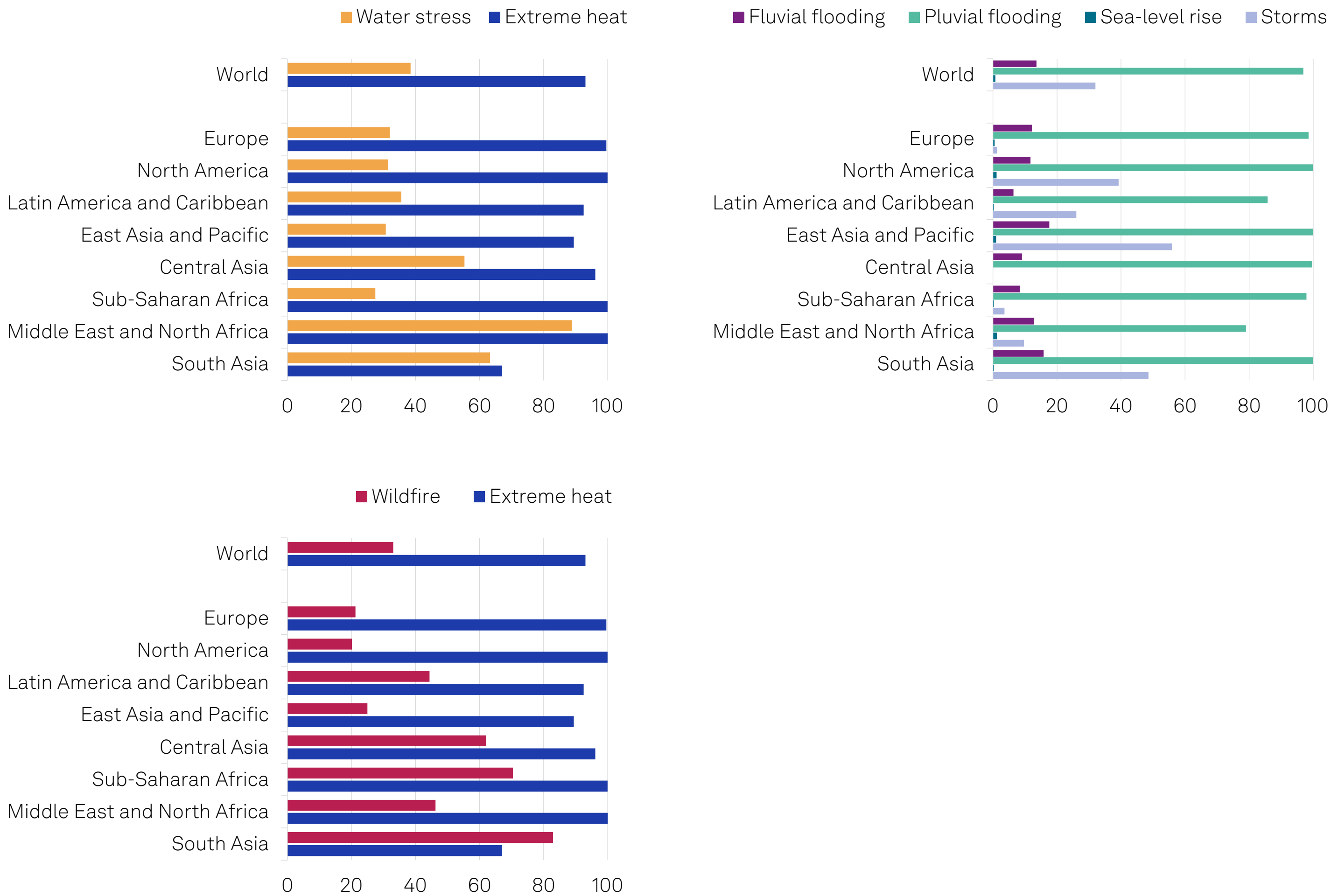
While there is still significant uncertainty regarding the timing and manifestation of impacts following physical climate risk events (among other dynamics), our scenario analysis provides a forward-looking view on the rising co-occurrence of compound events.

Compound climate hazard events are more likely to occur in regions most exposed to physical climate risks, and broadly reflect local specificities (see charts 11a, 11b, and 11c). In South Asia, all hazard pairs are becoming more likely. In MENA and Central Asia, the combination of water stress and pluvial floods or extreme heat, as well as wildfire and extreme heat, are the most dominant hazard pairs. By contrast, in Sub-Saharan Africa, the main hazard pair appears to be the joint occurrence of wildfire and extreme heat, although we note evidence that extreme heat and fluvial/pluvial flooding are expected to be dominant hazards (see IPCC, 2022b). Elsewhere, the risk of extreme heat and water stress is set to be more pronounced in most regions, and one of the more prominent hazard pairs in Europe and North America. In line with historical trends, North America, East Asia and Pacific, and the Caribbean also appear more at risk of seeing a combination of storms and floods, which points to a greater exposure of these regions to compound flooding and storms. For small island developing states included in our analysis, GDP exposure to storms and sea-level rise predominantly drives exposure. Note that we do not include projections of storms beyond the 2040s in our analysis, due to high uncertainty associated with this climate hazard.

Charts 11a, b, and c

Climate hazards are likely to occur simultaneously as their frequency rises

Climate hazard pairs by annual exposure (% of GDP or population) under a slow transition scenario (SSP3-7.0) in 2050, absent adaptation



Note: Exposure quantifies the share of GDP or population likely to be affected by climate hazards.
SSP3-7.0--Moderate-to-high emissions scenario. Sources: S&P Global Ratings, S&P Global Sustainable1 (2023).

The simultaneous occurrence of climate hazards could lead to more disruption than our GDP at risk metric suggests. As with the assessment of economic losses from single climate hazards, impacts will likely vary depending on economic structures and incomes. That said, on average, the total damage caused by individual hazards occurring together is likely to be larger than the sum of individual shocks. In the short term, compound events--by exacerbating each other--can amplify their individual impacts within countries and regions. There appears to be an increased likelihood of simultaneous crop failure in global breadbaskets resulting from higher temperatures in 1.5 C and 2 C scenarios (Gaupp et al.; 2019). These simultaneous weather extremes point to a larger impact on global food security, prices, and growth than if they were to happen on their own. In the medium term, climate hazards that compound each other are more likely to lead to permanent economic losses. This is because compound climate hazards require more resources to cope with and recover from, especially when adaptation is insufficient, but they also weigh on confidence and increase uncertainty about the future.

Physical Climate Risks Curb Output For Vulnerable Economies

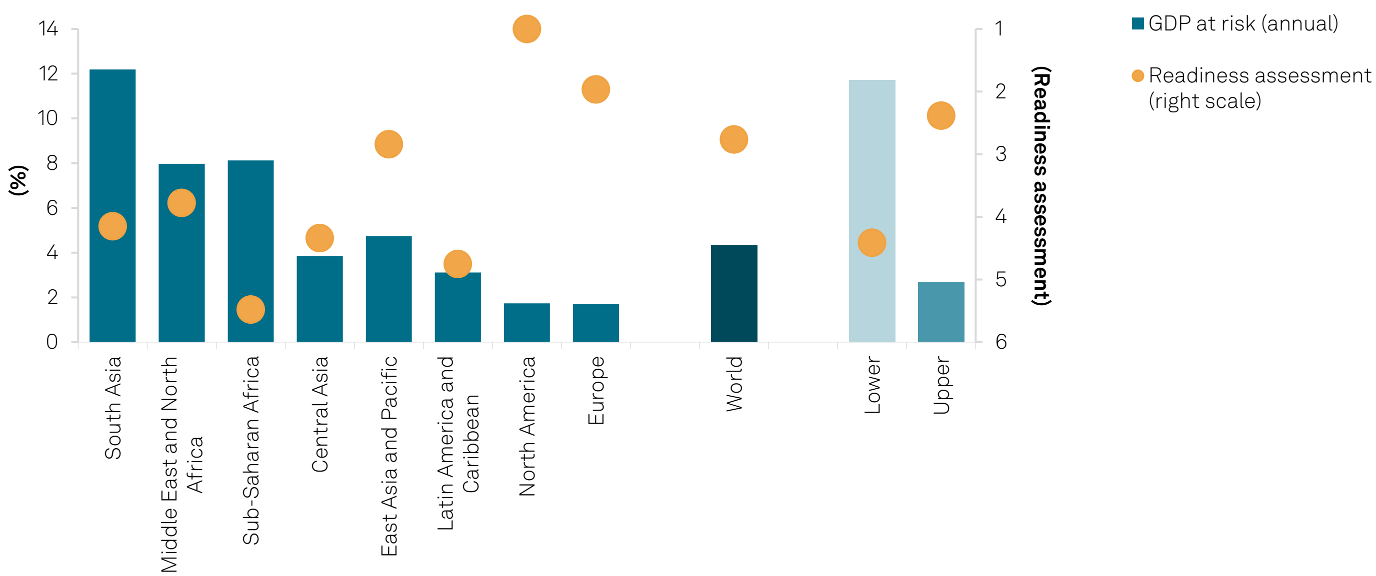
Our readiness metric helps to explain why current economic losses from physical climate risks can appear relatively low in some (typically more developed) economies, even though exposure to physical climate risks is high or GDP at risk significant. The readiness metric is on a scale of 1-6, where 1 denotes the highest degree of readiness, and 6 the lowest.

Our findings show that higher-income countries are better placed than lower-income nations to soften the impact of physical climate risks and recover. This is thanks to the former's greater financial means and stronger institutions. For lower- and lower-middle-income countries, our readiness assessment (see the Appendix for a definition) averages 4.5 compared to 2.4 for upper- and upper-middle income countries (see chart 12). This is notably the case in Hong Kong, which has 100% GDP exposure to storms due to the high frequency of typhoons (which occur about 8 times per year) and a readiness assessment of 2. The impact of storms on GDP are close to zero and mainly linked to the policy response, which suspends economic activity (see Zhou and Zhang 2021). Besides having a mostly services-based economy, Hong Kong is relatively sheltered to storm risk because its strong institutions and high financial means have already helped address this issue. For some countries, high readiness also implies that a significant proportion of resources are likely already dedicated to adaptation and resilience measures. Another example of readiness is in the Gulf Cooperation Council (GCC), where extreme heat and water stress are already serious issues. However, large financial means have enabled GCC countries to cope, for instance through the installation of air conditioning and water desalination.

Chart 12

On average, economic losses will be greater for lower-income regions

GDP at risk and readiness by region under a slow transition scenario (SSP3-7.0) in 2050, absent adaptation



Notes: GDP at risk represents the share of GDP that could be lost annually due to high exposure to physical climate risks, in the absence of adaptation to climate risk, without accounting for changes in the economic geography and structure and assuming all hazards occur every year. Readiness provides a relative picture of countries' ability to avoid and respond to some of these losses based on their economic and institutional strength. Readiness goes from 1 to 6, where a higher number points to lower capacity to adapt. SSP3-7.0--Moderate-to-high emissions scenario. Sources: S&P Global Ratings, S&P Global Sustainable1 (2023).

However, the costs of adaptation and resilience vary. Upper- and upper-middle income countries may expect greater absolute costs. But when expressed as a proportion of countries' GDP, adaptation costs are much greater for lower-income countries (about 3.5% per year), than for lower-middle (0.7%) or upper-middle income countries (0.5%), according to UNEP (2023).

Our analysis suggests investments in adaptation and resilience are likely to become increasingly important as absolute hazards become more extreme--both in terms of intensity and frequency in many regions--with some risks becoming hard to adapt to entirely. Limits to adaptation--that is, the point at which objectives or system needs cannot be saved from intolerable risks through adaptation (see Klein et al. 2014)--suggests some areas may be unable to be protected. An example is inability to protect low-lying islands from sea-level rise due to economic and physical limits, when expected costs exceed the impacts averted. This may be a particular challenge for more vulnerable countries, emphasizing the urgency of adaptation and resilience investments in the short term.

With poorer economies likely to struggle to cope with and adapt to more frequent and severe climate hazards, the burden of impacts will fall disproportionately on those most vulnerable. This reinforces our earlier findings that economic development and resilience to climate change feed off each other. In extreme cases, if reconstruction capacity is low, the economy could be caught in a poverty trap, in which it is unable to rebuild completely between each disaster (see Hallegate et al. 2009). In such cases, infrastructure may never fully recover. Reconstruction challenges are exacerbated in countries least ready to cope, with amplification of impacts more likely to arise from socioeconomic events (such as migration or conflict) aside from natural compound climate hazards (see International Monetary Fund, Working Paper No. 2022/054). Sub-Saharan Africa, where many fragile and conflict-prone states are located, seems most at risk, with the lowest readiness (5.5).

More vulnerable countries need external help to overcome the challenges physical climate risks pose for economic growth. In particular, data shows that low-income countries have contributed relatively little to the climate problem. Multilateral development banks can play a role in providing external help and support. The World Bank has recognized this issue in its new country climate and development reports, and stressed in a 2022 publication that climate change poses a threat to long-term development goals. As echoed by our readiness assessment, the World Bank also finds that countries facing challenges associated with physical climate risks and economic development may be highly reliant on a number of factors to adapt and cope, such as policy reforms, reallocation of scarce public resources, greater mobilization of private capital, and increased financial support from the international community.

What This Means In The Context Of Sovereign Credit Ratings

Consistent with its criteria, S&P Global Ratings incorporates the adverse physical effects of climate change--along with all other factors that could be relevant and material to creditworthiness--into its credit analysis. We do this when we believe such factors could materially influence the creditworthiness of a rated entity, or issue, and we have sufficient visibility on how those factors will evolve or manifest. As such, changes affecting climate risk can influence sovereign ratings and outlooks and may directly affect three of the pillars of our analysis, namely the economic, external and fiscal assessments, and indirectly affect other credit rating factors (see "Sovereigns: Sovereign Rating Methodology, " Dec. 18, 2017). We have previously described how changes affecting climate risk can influence sovereign ratings and outlooks (see "ESG Overview: Global Sovereigns," Feb. 3, 2021).

The scenarios in this paper provide fresh insight into the potential exposure and readiness of different countries to different types of climate risk. Climate risk accounts for just one set of risks, while the sovereign credit rating captures all credit factors as described in our sovereign rating criteria. Different countries will have differing levels of buffer to absorb the impacts of physical climate risks. In addition, there is uncertainty about future policy responses that governments may take to manage and adapt to such risks. Given these uncertainties, we do not consider the scenario analysis in this research to be part of our base case for sovereign ratings.

The findings from our scenario analysis reinforce our view that physical climate risks are likely to become more material in our sovereign rating analysis over time. They may be both a source of economic losses and a potential drag on fiscal budgets as recovery and adaptation needs increase. As chronic and acute risks become more frequent and severe, better data will become available, and uncertainty about the materialization of impacts will likely decline. A detailed analysis of the specific risks facing each country can help policymakers pursue more-targeted policies. It can also facilitate greater transparency in evaluating possible credit risk, for example, by putting greater emphasis on the ability and willingness of governments to actively seek to mitigate the negative impacts of climate risks and pursue effective adaptation strategies.

Financing adaptation and resilience to prevent the rising economic costs of physical climate risks will become more challenging in an environment of higher interest rates. Investors are now choosing relatively low-risk assets --mainly in advanced economies--that offer attractive returns rather than taking on higher risk in emerging markets and low-income countries (see "Global Credit Conditions Q4 2023 Resilience Under Pressure," Sept. 28, 2023). This is likely to tighten general and adaptation-related financing conditions further in the most vulnerable countries, which--according to our readiness assessment and ratings--are already more likely to be in the speculative-grade category. Adding to that, transition finance needs are also sizeable, corresponding to around 12% of total investments in emerging markets and developing economies, according to a report from the IMF in October 2023 (see IMF, 2023b).

Looking Ahead

In this research, we show that physical climate risks (both chronic and acute), which are becoming more frequent and severe, will affect more countries and regions, and have a greater adverse impact on those most vulnerable. As the potential associated damage rises, this will test countries' adaptation plans and their ability to recover without incurring permanent losses as a result of physical climate risks.

The rising likelihood of compound climate hazards adds to the challenges in climate analytics. Understanding these non-linear dynamics--especially in the context of countries' unequal exposure and diverging readiness to face those risks--appears crucial to assess and understand how countries most exposed can prepare (also see NGFS 2023b).

The adaptation gap is widening, given slow progress on preparedness, and financing conditions are tightening. Financing rising adaptation costs as the impacts of climate hazards worsen may become more challenging in an environment of higher interest rates, adding another hurdle to developing countries' adaptation implementation.

Related Research

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- Is Climate Change Another Obstacle To Economic Development?, Jan. 16, 2023
- Climate Change Will Increase Output Volatility, Jan. 5, 2023
- Weather Warning: Assessing Countries' Vulnerability To Economic Losses From Physical Climate Risks, April 27, 2022
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Appendix

Full results are presented in table A1, with a description of our approach and limitations described thereafter.

Table A1

Complete results for all 137 rated entities under SSP3-7.0 in 2050

			GDP exposure (%)						Population exposure (%)
Rated entities	Region	Readiness	Sea-level rise	Fluvial flooding	Pluvial flooding	Storms	Water stress	Wildfire	Extreme heat
Kazakhstan	Central Asia	4	0	10	99	0	39	55	94
Tajikistan	Central Asia	6	0	13	100	0	46	88	100
Uzbekistan	Central Asia	5	0	8	100	0	84	77	100
Australia	East Asia and Pacific	1	1	13	100	35	72	47	58
China	East Asia and Pacific	3	1	18	100	36	39	30	85
Cook Islands	East Asia and Pacific	4	N/A	N/A	N/A	N/A	N/A	N/A	100
Fiji	East Asia and Pacific	5	1	22	100	100	N/A	1	100
Hong Kong	East Asia and Pacific	2	3	3	100	100	0	0	100
Indonesia	East Asia and Pacific	4	1	23	100	69	30	26	100
Japan	East Asia and Pacific	2	3	16	100	100	0	0	99
Malaysia	East Asia and Pacific	3	0	17	100	13	0	0	100
Mongolia	East Asia and Pacific	5	0	12	100	0	94	27	100
New Zealand	East Asia and Pacific	1	0	28	100	100	0	0	100
Papua New Guinea	East Asia and Pacific	6	1	13	100	57	0	1	100
Philippines	East Asia and Pacific	4	2	10	100	100	44	30	100
Singapore	East Asia and Pacific	1	1	4	100	0	0	0	100
South Korea	East Asia and Pacific	2	1	8	100	100	35	0	100
Taiwan	East Asia and Pacific	2	2	20	100	100	0	4	100
Thailand	East Asia and Pacific	4	0	31	100	80	51	76	85
Vietnam	East Asia and Pacific	4	2	26	100	86	10	45	100
Albania	Europe	4	2	12	100	0	98	76	100
Andorra	Europe	2	0	21	100	0	100	100	100
Armenia	Europe	4	0	7	100	0	87	73	100
Austria	Europe	1	0	17	100	0	0	0	100
Azerbaijan	Europe	5	0	11	100	0	77	74	100
Belgium	Europe	2	0	14	100	0	87	0	100
Bosnia and Herzegovina	Europe	4	0	11	100	0	0	90	100
Bulgaria	Europe	4	1	5	100	0	74	76	100
Croatia	Europe	4	1	14	100	0	0	29	100
Cyprus	Europe	2	1	0	100	0	99	60	100
Czech Republic	Europe	3	0	7	100	0	10	0	100

			GDP exposure (%)						Population exposure (%)
Rated entities	**Region**	**Readiness**	**Sea-level rise**	**Fluvial flooding**	**Pluvial flooding**	**Storms**	**Water stress**	**Wildfire**	**Extreme heat**
Denmark	Europe	1	2	13	100	0	0	0	100
Estonia	Europe	3	0	13	100	0	76	0	100
Finland	Europe	1	0	27	100	0	3	0	100
France	Europe	1	0	11	100	0	44	27	100
Georgia	Europe	4	2	16	100	0	47	33	100
Germany	Europe	1	0	11	100	0	3	0	100
Greece	Europe	3	1	19	100	0	90	55	100
Guernsey	Europe	2	N/A	N/A	N/A	N/A	N/A	N/A	100
Hungary	Europe	3	0	11	100	0	13	42	100
Iceland	Europe	2	2	10	100	0	0	0	100
Ireland	Europe	1	1	12	100	0	0	0	100
Italy	Europe	3	1	13	100	0	54	37	100
Jersey	Europe	2	N/A	N/A	N/A	N/A	N/A	N/A	100
Latvia	Europe	3	2	13	100	0	0	0	100
Liechtenstein	Europe	1	0	40	100	0	0	0	100
Lithuania	Europe	3	0	7	100	0	62	0	100
Luxembourg	Europe	1	0	4	100	0	11	0	100
Macedonia	Europe	4	0	15	100	0	100	85	100
Montenegro	Europe	4	0	15	100	0	41	95	100
Netherlands	Europe	1	5	40	100	0	27	0	100
Norway	Europe	1	1	41	100	0	0	0	98
Poland	Europe	3	0	7	100	0	22	0	100
Portugal	Europe	3	1	7	89	51	85	73	100
Romania	Europe	4	0	10	100	0	56	65	100
Saint Helena	Europe	5	N/A	N/A	N/A	N/A	N/A	N/A	100
Serbia	Europe	4	0	16	100	0	18	87	100
Slovakia	Europe	3	0	18	100	0	13	4	100
Slovenia	Europe	3	0	10	100	0	0	0	100
Spain	Europe	2	0	7	78	9	68	67	100
Sweden	Europe	1	1	27	100	0	0	0	90
Switzerland	Europe	1	0	9	100	0	0	0	100
Turkey	Europe	4	1	10	100	0	86	61	100
Ukraine	Europe	5	0	7	100	0	34	56	100
United Kingdom	Europe	1	0	6	100	0	0	0	100
Argentina	Latin America and Caribbean	5	0	8	99	0	11	46	31
Aruba	Latin America and Caribbean	5	0	N/A	0	100	N/A	1	100
Bahamas	Latin America and Caribbean	4	2	0	100	100	0	1	100

			GDP exposure (%)						Population exposure (%)
Rated entities	Region	Readiness	Sea-level rise	Fluvial flooding	Pluvial flooding	Storms	Water stress	Wildfire	Extreme heat
Barbados	Latin America and Caribbean	5	0	0	0	100	N/A	0	100
Belize	Latin America and Caribbean	6	0	0	36	100	9	66	100
Bolivia	Latin America and Caribbean	6	0	8	100	0	10	62	100
Brazil	Latin America and Caribbean	5	0	6	100	0	25	42	100
Chile	Latin America and Caribbean	4	0	1	15	0	90	49	95
Colombia	Latin America and Caribbean	4	0	6	98	13	0	9	100
Costa Rica	Latin America and Caribbean	4	0	0	74	99	0	14	100
Curaçao	Latin America and Caribbean	5	0	0	0	100	N/A	71	100
Dominican Republic	Latin America and Caribbean	3	0	0	0	100	2	64	100
Ecuador	Latin America and Caribbean	5	0	11	100	0	0	4	100
El Salvador	Latin America and Caribbean	5	0	0	100	95	20	88	100
Falkland Islands	Latin America and Caribbean	2	2	47	100	0	N/A	0	100
Guatemala	Latin America and Caribbean	5	0	5	100	100	45	75	100
Honduras	Latin America and Caribbean	5	0	2	89	69	0	73	100
Jamaica	Latin America and Caribbean	6	1	0	0	100	N/A	25	100
Mexico	Latin America and Caribbean	5	0	7	94	45	78	54	100
Montserrat	Latin America and Caribbean	5	N/A	N/A	N/A	N/A	N/A	N/A	100
Nicaragua	Latin America and Caribbean	5	0	0	93	100	0	72	100
Panama	Latin America and Caribbean	2	0	8	100	97	0	6	100
Paraguay	Latin America and Caribbean	5	0	4	100	0	0	9	100
Peru	Latin America and Caribbean	4	0	26	100	0	14	38	100
Suriname	Latin America and Caribbean	6	3	0	94	79	0	0	100
Trinidad and Tobago	Latin America and Caribbean	4	0	0	0	100	0	31	100
Turks and Caicos Islands	Latin America and Caribbean	4	0	0	100	100	0	0	100
Uruguay	Latin America and Caribbean	3	0	3	100	0	0	7	45
Abu Dhabi	MENA	2	5	23	100	9	92	4	100
Bahrain	MENA	4	5	1	100	0	88	5	100
Egypt	MENA	5	3	1	3	0	81	75	100
Iraq	MENA	6	0	33	100	0	62	55	100
Israel	MENA	2	0	0	26	0	97	65	100
Jordan	MENA	6	0	0	22	0	100	46	100
Kuwait	MENA	3	1	33	100	0	98	16	100
Lebanon	MENA	6	0	32	100	0	93	59	100
Malta	MENA	3	0	0	100	0	99	64	100
Morocco	MENA	5	0	0	2	55	87	75	100
Oman	MENA	4	1	29	100	99	97	52	100
Qatar	MENA	2	1	6	100	0	99	10	100

			GDP exposure (%)						Population exposure (%)
Rated entities	**Region**	**Readiness**	**Sea-level rise**	**Fluvial flooding**	**Pluvial flooding**	**Storms**	**Water stress**	**Wildfire**	**Extreme heat**
Ras Al-Khaimah	MENA	3	22	19	100	100	81	30	100
Saudi Arabia	MENA	3	0	8	97	0	88	28	100
Sharjah	MENA	3	2	82	100	100	100	4	100
Bermuda	North America	2	6	N/A	100	100	N/A	0	100
Canada	North America	1	0	22	100	5	13	5	100
United States	North America	1	1	11	100	42	33	22	100
Bangladesh	South Asia	4	1	28	100	88	3	85	45
India	South Asia	4	0	15	100	48	66	85	63
Pakistan	South Asia	5	0	16	100	26	72	79	100
Sri Lanka	South Asia	6	0	10	100	87	79	37	100
Angola	Sub-Saharan Africa	6	0	4	100	0	45	63	100
Benin	Sub-Saharan Africa	5	1	7	100	0	0	86	100
Botswana	Sub-Saharan Africa	5	0	5	100	0	91	86	100
Burkina Faso	Sub-Saharan Africa	6	0	3	100	0	79	86	100
Cabo Verde	Sub-Saharan Africa	5	2	N/A	0	94	N/A	92	100
Cameroon	Sub-Saharan Africa	5	0	11	100	0	0	55	100
Congo	Sub-Saharan Africa	6	0	12	100	0	0	34	100
Côte d'Ivoire	Sub-Saharan Africa	4	1	4	100	0	0	59	100
Democratic Republic of the Congo	Sub-Saharan Africa	6	0	7	100	0	0	56	100
Ethiopia	Sub-Saharan Africa	6	0	6	100	2	20	96	100
Ghana	Sub-Saharan Africa	5	1	10	100	0	6	52	100
Kenya	Sub-Saharan Africa	4	0	6	100	0	2	76	100
Madagascar	Sub-Saharan Africa	6	0	10	100	100	2	88	100
Mauritius	Sub-Saharan Africa	3	0	N/A	100	100	N/A	1	100
Mozambique	Sub-Saharan Africa	6	0	11	100	70	31	76	100
Nigeria	Sub-Saharan Africa	6	1	11	100	0	17	68	100
Rwanda	Sub-Saharan Africa	5	0	7	100	0	0	70	100
Senegal	Sub-Saharan Africa	4	1	0	100	0	61	66	100
South Africa	Sub-Saharan Africa	5	0	3	90	4	52	72	100
Togo	Sub-Saharan Africa	6	0	5	100	0	2	81	100
Uganda	Sub-Saharan Africa	6	0	3	100	0	8	52	100
Zambia	Sub-Saharan Africa	6	0	5	100	0	10	86	100

Note: Pink to purple coloring indicates lower to high exposure. MENA--Middle East and North Africa. N/A--Not applicable (GDP data not available in Kummu et al. 2018). SSP3-7.0--Moderate-to-high emissions scenario. Source: S&P Global Ratings (2023).

Data And Approach

Disentangling the relationship between physical climate risks and the economy can be quite complex and even harder to foresee, especially since other trends are likely to be more visible drivers of economic development over the next decades.

Research approach

Despite advances in climate science in recent years--particularly in understanding both the direction and magnitude of change of specific climate variables--today's climate models have inherent limitations. In particular, they cannot predict the precise timing or severity of the manifestation of chronic or acute physical climate risks that could bring economic damage or disruption. As such, considering a variety of scenarios and time points in forward-looking analyses enables us to understand countries' possible future exposures.

We therefore used **scenario analysis** since it facilitates a forward-looking understanding of the intensification of physical climate risks, all other things being equal. The seven climate hazards used in our scenarios are: extreme heat, fluvial (river) flooding, pluvial (rainfall) flooding, sea-level rise, water stress, wildfire, and storms.

Through our analysis, we seek to uncover some of the transmission channels and non-linear impacts of climate hazards, adaptation to physical climate risks, and economies' recovery potential through the lens of three metrics:

- **Exposure.** This metric quantifies the share of GDP or population likely to be affected by climate hazards. It captures the location-specific dimension of climate by mapping where specific physical risks will likely occur and where such hazards intersect with the geography of economic resources today.
- **GDP at risk** represents the share of GDP that could be lost annually due to exposure to physical climate risks. It is based on a static view of the economy, so it doesn't account for adaptation to climate risk, changes in economic geography, economic structure, or any other growth dynamics. It also assumes all hazards occur every year.
- **Readiness** measures the ability of countries to avoid, respond to, and recover from physical climate risks**.** It is a proxy measure that is based on the countries' economic and institutional strength. The proxy is country specific and intrinsically linked to the level of development. Readiness is on a scale of 1 to 6, where 1 denotes the highest capacity to adapt and 6 the lowest capacity to adapt.

Each metric can be looked at separately but, taken together, they provide a relatively holistic picture of potential impacts and capacity to adapt to physical climate risks.

Data sources

- Economic, financial, and other data on the 137 countries we rate, including institutional and economic assessments.
- S&P Global Sustainable1 Physical Risk dataset. This data is derived from publicly available information, licensed datasets, and Sustainable1's own models. It doesn't model the probability of the climate hazards occurring individually or jointly.
- New climate hazard modelling data (output from the latest set of climate models, CMIP6, as used by the IPCC's AR6), which are driven by various modelling assumptions. Climate hazard

data focuses attention on hazard exposures that are attributable to climate change, rather than hazards that were present historically in a pre-climate-change state.

- Forward-looking projections of storms and pluvial (severe rainfall) flooding and a more granular dataset. In addition, all climate hazards are now projected to the end of the century; water stress and storms are projected to the 2040s and held constant thereafter.

Due to uncertainties associated with longer-term projections, we limit our analysis to the mid-century, presenting findings--where appropriate--using a later time point as a means of comparison.

Defining countries' exposure to climate hazards

The exposure metric captures the geographic location of economic output (GDP distribution) and labor force (population distribution) within each country at a resolution of between 300 meters and 1 kilometer. This is overlaid with areas of high exposure to each climate hazard (see table A2) under the four SSPs (SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5) and time points (baseline and each decade through to 2100).

The GDP and population distribution used are based on values from 2015 (from Kummu et al. 2018) and 2020 (NASA), respectively. The hazard thresholds provide a conservative estimate of the proportion of physical and human capital exposed to physical climate risks.

Table A2

Thresholds for each climate hazard

Climate hazard	Type	Threshold	Rationale
Sea-level rise	Projected frequency of the 1-in-100-year coastal flood depth	0.01	Non-zero exposure to sea-level rise
Extreme heat	Projected annual fraction of days with maximum temperature warmer than the 95th percentile local baseline daily maximum temperature	0.123	Approximately six weeks of extreme heat days per year
Fluvial flood	Severe river flooding--projected frequency of the 1-in-100-year historical baseline flood depth	0.01	Non-zero exposure to fluvial (river) floods
Pluvial flood	Severe precipitation--projected frequency of the historical 100-year flood depth	0.01	Non-zero exposure to pluvial floods
Storms (hurricane, typhoon or cyclone)	Annual frequency. For example, for tropical cyclone, the projected annual frequency of Category 3 or greater events	0	Non-zero exposure to storms
Water stress	Projected future ratio of water withdrawals to total renewable water supply in a given area	0.4	World Resources Institute (WRI) threshold for high water stress
Wildfire	Annual frequency--projected annual fraction of days where the fire weather index is classified as high or above	0.082	Approximately seven weeks of wildfire conditions per year
Combined	As above	As above	Exposure to physical risks above the threshold for any of the climate hazards noted above

Source: S&P Global Ratings.

Calculating GDP at risk

GDP at risk is a function of the exposure metric to which an impact loss coefficient is applied. Impact coefficients for the GDP impact of climate hazards associated with flooding and storms (high winds) are differentiated for low-middle- and high-middle-income countries and taken from Formetta and Feyen's 2019 study. For labor-productivity-related GDP loss, impact coefficients are differentiated by country and major sectors according to work from Roson and Satori (2016). A unitary coefficient for the GDP impact of wildfires is taken from Meier's 2023 report.

The GDP at risk figure does not do well at identifying the transmission channels of physical climate risks to the economy. Since the economy is not modelled, it doesn’t account for feedback effects running through the economy. Similarly, it doesn't capture any potential adaptation and resilience interventions, or a reorganization of sectoral value added and the changing geography of activity. The productivity channel is the main factor influencing the GDP at risk related to extreme heat, while--for acute risks--the numbers mostly capture damage to capital stock. Yet, those may not lead to a linear drop of growth.

Our approach disaggregates GDP impact estimates for a sea-level rise, fluvial flooding, pluvial flooding, wildfire, and storms, rather than summing impacts for those hazards. The implication is that GDP losses are more granular, and this adds some uncertainty to estimates since the approach implicitly assumes that GDP is exposed to single hazards, rather than all hazards occurring simultaneously.

Assessing readiness of individual countries to adapt to physical climate risks

To do this, we use S&P Global Ratings' institutional and economic assessments, which results from credit analysis using our sovereign credit rating methodology. Those assessments can provide insight on the institutional and financial capacity of countries to invest in adaptation and respond to physical climate risks. Sovereign readiness is a time-point estimate based on countries' economic and institutions of today.

Our economic assessment, anchored in GDP per capita, captures a country’s level of economic development, which in turn offers insight into its past and current ability to meet various policy challenges. It also reflects a country's growth prospects, and economic diversity and volatility. Our economic assessment is associated with the economic and financial resources available to a sovereign entity that may be mobilized to mitigate risks, including physical climate risks. While economic strength is not a perfect proxy of a sovereign’s willingness and capacity to proactively address physical climate risks, it is strongly correlated with broadly accepted measures of readiness to adapt to physical climate risks, such as the ND-GAIN Index.

To account for the relative importance of institutions in dealing with climate hazards, in cases where there is a large gap between our assessments of economic strength and institutional effectiveness under the sovereign rating methodology, we reflect that divergence by revising the economic assessment down by one level. This allows us to arrive at an adjusted measure of the sovereign’s capacity to address the long-term impacts of physical climate risks--a proxy, in our view, of countries’ readiness to adapt.

Our sovereign institutional assessment considers, among other things, the effectiveness, stability, and predictability of policymaking, political institutions, and civil society. We believe that effective policymaking and stable political institutions better enable governments to address periods of economic distress and take measures to correct imbalances, including risks arising from climate change and the energy transition, which in turn help to sustain long-term growth prospects.

Limitations

As with any long-term estimation of future events, there are some inherent uncertainties associated with climate science, including the crystallization and severity of climate risks (see "Model Behavior: How Enhanced Climate Risk Analytics Can Better Serve Financial Market Participants," June 24, 2021, which describes some of these uncertainties and potential mitigants). Adding to that, the literature on the economics of climate change still faces sizable data availability and modeling constraints.

We describe some of the limitations and assumptions of our analysis below:

- The model provides a comparative estimate of economic impact using static linear coefficients to model country GDP at risk across all scenarios and time periods. Applied at the country level, impact coefficients are imprecise, given that they are based on historical averages of losses that do not control for other dynamics and may be more focused on estimating wealth effects than on potential output impacts. For some large countries, the estimates may mask subnational variation. Focusing on average damage levels also masks the uncertainty surrounding the wider distribution of risk. Adding to that, future levels of GDP at risk do not account for changes in a country's geography of economic resources, while transmission channels and second-round effects are not well captured through this static approach.
- The model assumes the impacts of climate hazards on GDP at risk are independent, that is, the likelihood of occurrence and associated impact of a specific climate hazard is unrelated to the annual frequency and impact of all other climate hazards.
- The definition of an extreme condition or event remains constant for a given location over time, without variation in other dimensions, for example flood depth or potential for successive days of extreme heat. Exposure to extreme risks is also defined as binary variables and normalized at the global level over a long period (2020-2090) and thus hides a large increase of risk in the tail once the threshold is already exceeded.
- We intentionally exclude impacts from earthquakes and volcanic activity due to limited links of these types of natural disasters with climate change. We note that some evidence is emerging linking seismic activity with climate change, although this is at a nascent stage.
- Aside from physical climate risks, countries are also exposed to transition risks. Some countries are proactively managing the transition away from fossil fuels, shifting resources to promote greener growth, with some setting net zero targets to 2050 or earlier to align with the Paris Agreement (see "Economic Research: Green Spending Or Carbon Taxes (Or Both): How To Reach Climate Targets, And Grow Too, By 2030?" Nov. 4, 2021, for a discussion of current transition policies). The changing geopolitical landscape could also help crystallize transition risks sooner for countries with greater exposure. Although we note the materiality of transition risks, we intentionally exclude them in the analysis for this research to concentrate on countries' vulnerability to the physical impacts of climate change. To gain a comprehensive understanding of countries' vulnerability to climate risks, both transition and physical climate risks should be considered.

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