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ESG Research

Weather Warning: Assessing Countries' Vulnerability To Economic Losses From Physical Climate Risks

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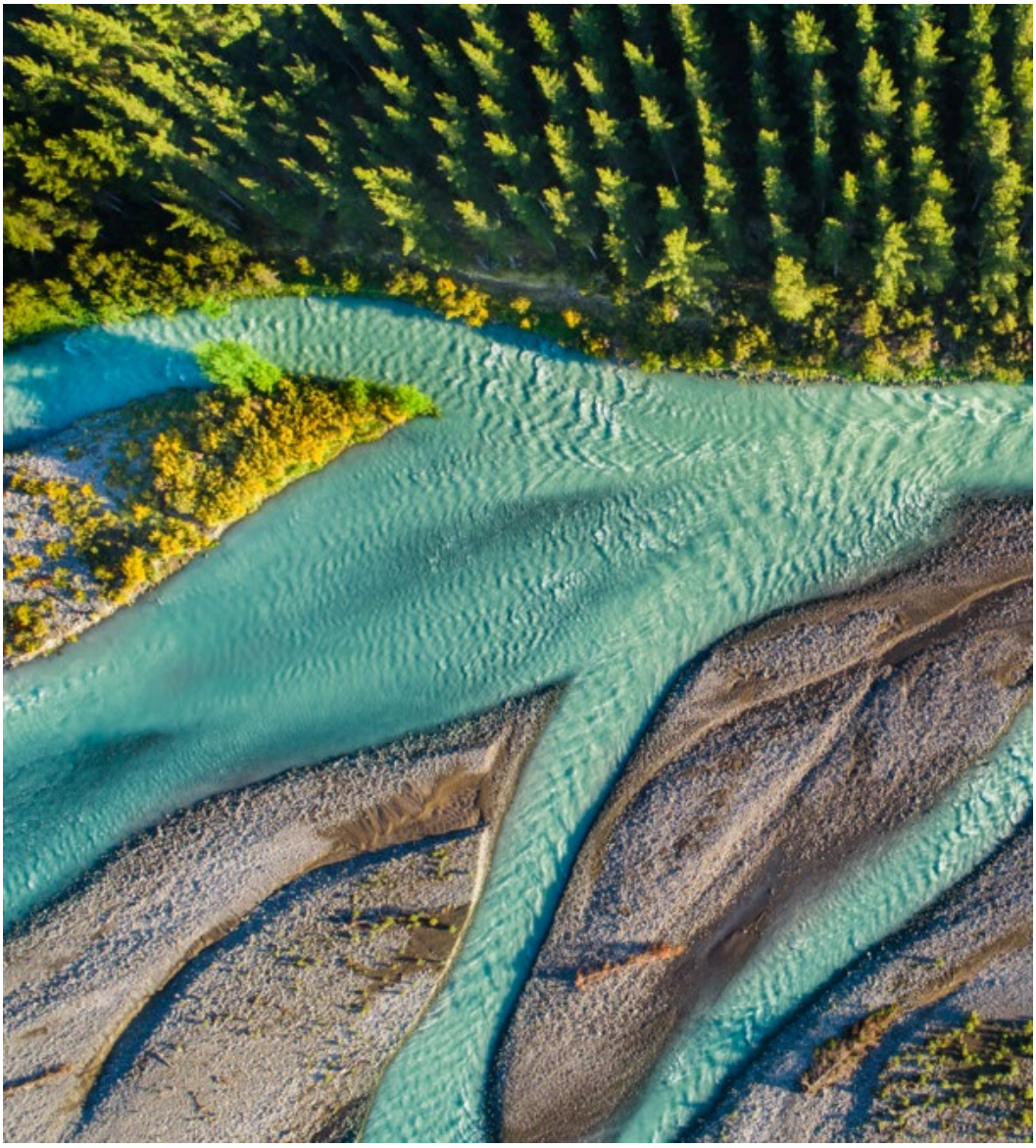
This report does not constitute a rating action.



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Key Takeaways

- In an exploratory scenario analysis of the vulnerability and readiness of 135 countries to climate change over the next 30 years, S&P Global Ratings finds that physical climate risks could expose 3.3%, 4%, and 4.5% of world GDP to losses by 2050 under climate pathways RCP2.6 (Paris Agreement), RCP4.5 (current policies), and RCP8.5, assuming no adaptation and all risks materialize simultaneously.
- Vulnerability and readiness vary widely by region and country:
  - Our vulnerability assessment finds that regional impacts from climate hazards differ and are most pronounced in South Asia (10%-18% of GDP at risk) and is high for Central Asia, Middle East and North Africa, and Sub-Saharan Africa.
  - Our economic loss estimates show that lower- and lower-middle income countries are likely to see 3.6 times greater losses on average than higher-middle- and higher-income countries. Adding to that, our readiness assessment highlights that economic losses are likely to be higher and more persistent for those same countries, which have less capacity to adapt, more precisely, weaker institutions and less financial capacity.
- International cooperation and support can help the most vulnerable countries to finance a rising adaptation gap while building resilience to climate change, a problem to which they have contributed relatively little.
- Given the uncertainties inherent in climate science, we do not consider this scenario analysis as part of our base case for sovereign ratings. S&P Global Ratings incorporates the adverse physical effects of climate change, where material and visible and regardless of the time horizon, into the analysis. This scenario analysis aims to provide insights into the potential exposure and readiness of different sovereigns to different types of climate risk.

For most countries, exposure to, and costs from, the physical impacts of climate change are increasing. Over the past 10 years, storms, wildfires, and floods alone have caused losses of around 0.3% GDP per year globally according to Swiss Re loss data. In the EU, recent heat waves have been associated with 0.3%–0.5% GDP losses (Garcia-Leon et al., 2021). The World Meteorological Organization (WMO) reports that, on average, a disaster related to weather, climate, or water occurred every day over the last 50 years, causing 115 daily deaths and over $202 million in daily losses. Further, more than 90% of all deaths associated with these disasters were in developing countries. Although the number of deaths has decreased threefold in this timeframe--thanks to early warning systems and better disaster management and preparedness--the frequency of such events has increased nearly five times in the last 50 years. If the current trend continues, the number of disasters could increase to 560 per year by 2030--an increase of 40% compared with 2015, according to the UN Office for Disaster Risk Reduction (2022). More recently, the sixth Intergovernmental Panel on Climate Change (IPCC) Assessment Report (AR6) from Working Group II found that between 3.3 billion and 3.6 billion people live in areas that are highly vulnerable to climate change, further reinforcing the need for adaptation.

Climate hazards, such as storms, flooding, wildfires, and heat waves can affect countries' wealth through direct damage to their physical capital stock and potential income flow--for example, heat waves can reduce labor productivity. Stock losses may result in using resources to rebuild, diverting investments away from innovation toward reconstruction activities. Over time, these missed productivity gains are likely to reduce the potential level of future incomes. Public finances may be particularly affected, as the response to climate shocks will likely require higher public spending and thus lead to greater debt burdens. Social impacts extend to security risks and governance structures that may be stressed by more frequent and severe acute risks (including wildfire, flooding, and storms—comprising hurricanes, typhoons, cyclones) and chronic risks (those manifesting over the medium to longer term, including changes to precipitation and temperature patterns and sea level rise). Both acute and chronic risks can contribute to migration flows, an example of a social impact that has been shown to present security risks and country's governance structures.

That said, for some countries, the physical impacts of climate change may begin to play out only over time--especially those with greater exposure to chronic risks, which we expect will become more severe over the years. Countries with economies more reliant on sectors such as agriculture are likely to bear greater impacts from physical climate risks. Countries around the

Editor's note

This paper represents a collaborative research project by the Sustainable Finance, Economics, and Credit Ratings teams at S&P Global Ratings to develop an exploratory scenario analysis to identify the potential impacts of physical climate risks on countries' economies.

equator or small islands tend to be more exposed than others, highlighting that geographical heterogeneity is a key driver of countries' different exposures to climate hazards.

We also note the pace and scale of adaptation action lags what is required, as reported by the IPCC's AR6 and the UN Environment Programme (UNEP) Adaptation Gap Report 2021 and as we discussed in "Sink Or Swim: The Importance Of Adaptation Projects Rises With Climate Risks," Dec. 3, 2019). The impacts and measures countries use to adapt to climate hazards so far mostly reflect their location, level of economic development, and civil societies' awareness of climate change.

Another component affecting countries' vulnerability is their readiness and ability to adapt as quickly as required. Factoring in countries' readiness to cope with the physical impacts of future climate change is still evolving. For our readiness metric, we use S&P Global Ratings' institutional and economic analysis for sovereigns and, where that is not available, the readiness indicator from the Notre Dame-Global Adaptation Index (ND-GAIN) Country Index, which shows strong correlation with our economic assessment (see "ESG Overview: Global Sovereigns," Feb. 3. 2021).

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 is at a nascent stage and still faces sizable data availability and modeling constraints.

Overview Of Our Approach

Here, S&P Global Ratings presents the findings of a new, global assessment of countries' vulnerability to the physical impacts of climate change, using the S&P Global Trucost Physical Risk dataset and other publicly available datasets. Using an exploratory scenario analysis, we evaluate the vulnerability of 135 countries to different climate hazards over the next 30 years (in terms of economic losses) and assess their readiness to adapt (that is, their capacity to mitigate and absorb the economic losses). This analysis contributes to understanding the scale of potential losses and their distribution across the globe.

Our approach characterizes countries' vulnerability to physical climate risks based on patterns of future exposure to climate hazards--heat waves, flooding, sea level rise, water stress, wildfire and storms (baseline only)--combined with the geographic location of economic output and population distribution. Using academic literature estimates of economic loss rates associated with these hazards, we estimate potential economic impacts at a regional level. Finally, we assess countries' readiness to adapt to physical climate risks using S&P Global Ratings' economic and institutional assessments for sovereigns.

Scenario Analysis May Help Countries Plan For An Uncertain Future

Despite advances in climate science in recent years, particularly 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 risks that could bring economic damage or disruption. As such, considering a variety of scenarios and timepoints in forward-looking analyses enables us to understand countries' possible future exposures.

Physical Climate Risks And Sovereign Ratings

When assessing sovereign creditworthiness, S&P Global Ratings incorporates the adverse physical effects of climate change, where material and visible, into our analysis. As such, changes affecting climate risk can influence sovereign ratings and outlooks and may directly affect the three 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 insight into the potential exposure and readiness of different sovereigns to different types of climate risk. Climate risk accounts for just one set of risks, while the credit rating captures all credit drivers as described in our sovereign rating criteria. Different sovereigns will have differing levels of buffer to absorb the impacts of physical climate risks. What's more, 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 this scenario analysis as part of our base case for sovereign ratings.

Transition Risks

Aside from physical 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 this paper's analysis 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 risks should be considered.

With this in mind, our scenario analysis uses multiple Representative Concentration Pathways (RCPs). According to the IPCC AR6, countries' current commitments to reduce greenhouse gas (GHG) emissions, as captured through Nationally Determined Contributions (NDCs), align to a global temperature increase close to that described by RCP4.5--assuming all actions pledged by countries are put into practice and policy. If countries meet both conditional and unconditional pledges for the near-term target of 2030, warming could be limited to 2.4 degrees Celsius by 2100 or 1.8°C if their long-term net zero promises are met, as reported by Carbon Brief at the COP26 climate change summit. In this paper, we primarily report findings using RCP4.5 and use the other RCPs to describe a range of possible outcomes, where appropriate. Owing to the availability of data and uncertainties inherent in long-term forecasts, our analysis focuses on changes from present day through to midcentury. That said, a certain amount of change is locked in due to the lag in the climate system owing to historic GHG emissions--many of the impacts of climate change will therefore materialize irrespective of the policy choices made today and absent adaptation. From 2050-2100, there is much greater divergence in emissions pathways between the RCPs, reflecting the relative impacts of policy choices taken now and in the near term.

Adding to uncertainties surrounding climate scenarios, the link is still being developed between climate change and its potential economic consequences. For now, most economic scenario modeling has relied on Integrated Assessment Models (IAMs), which have been largely criticized for their underlying assumptions. Newer panel-modeling approaches have focused on using historical evidence to assess potential losses associated with climate change. While the latter still fall short of the IAMs' dynamic approach, they tend to point to higher costs for climate change. For this scenario analysis, we chose to reflect the costs of physical climate risks as assessed by panel estimates (see our sources for those in the bibliography).

The main uncertainties surrounding our estimates of GDP at risk of losses stem from:

- Dynamic changes within countries' economies, for example, sectoral specialization changes, geographic relocation of activities and people, and changing consumption or investment behavior and trade patterns, which are not modeled;
- How much adaptation costs and helps avoid these losses; and
- Uncertainty associated with accurately measuring the economic impact of climate hazards.

There is emerging evidence that some of the countries' losses from the physical impacts of climate change permanently affect potential output (see Bakkensen and Barrage 2020), but evidence is mixed about whether they permanently lower countries' growth potential (Burke et al., 2015; Kalhuhl and Wenz 2020). That said, we note that our combined GDP at risk results are very close to the current policies scenario from the Network for Greening the Financial System (NGFS), which uses a dynamic modeling approach (that is, IAMs). They find global GDP losses close to 5% by 2050, arguably within the same range as our 4% GDP at risk estimates under RCP4.5 and 4.5% under RCP8.5, considering the associated uncertainty.

What Are Representative Concentration Pathways?

- RCP8.5 is a high emissions scenario, consistent with a future where no further policy action is taken to reduce GHG emissions. It is considered an extreme business-as-usual scenario resulting in an average global temperature increase of 3.7°C (likely range 2.6°C to 4.8°C).
- RCP6.0 is a high-to-moderate emissions scenario where GHG emissions peak around 2060 and then decline. An average global temperature increase of 2.2°C is projected (likely range 1.4°C to 3.1°C).
- RCP4.5 is a moderate emissions scenario consistent with a future of relatively ambitious emissions reductions with a slight rise to 2040 and then a decline. This scenario falls short of the Paris Agreement aim of limiting global temperature rise to "well below" 2°C, with a projected average temperature increase of 1.8°C (likely range 1.1°C to 2.6°C).
- RCP2.6 is the only IPCC scenario that aligns with the Paris Agreement target to limit the average increase in global temperature to well below 2°C. This scenario is consistent with ambitious GHG emission reductions, peaking around 2020, then declining on a linear path to become net negative before 2100. An average global temperature increase of 1°C is projected (likely range 0.3°C to 1.7°C).

Furthermore, given the inherent uncertainty of projecting the probability of each physical risk occurring at any given point in time (and the precise impacts should such events play out), we don't model the probability of the various climate hazards occurring and we represent the risks for our regional analysis as additive, acknowledging that they may not all occur at the same time. Taking event probability into account would likely reduce our GDP loss estimates as the probability of each hazard happening at all locations in the areas defined as highly exposed is less than 1, and the joint probability that all climate hazards happen at the same time is even lower, although those risks are likely to be interdependent. All in all, the point estimates we provide should be viewed against this backdrop of uncertainty and are likely to evolve over time as countries adapt to a new climate landscape and climate and economic science improve their understanding of these risks. For this reason, we also consider that country estimates based on this methodology are uncertain. Therefore, we report economic loss estimates at the regional level only and focus on physical risk exposure and readiness at the country level.

Assessing Countries' Vulnerability To Physical Climate Risks

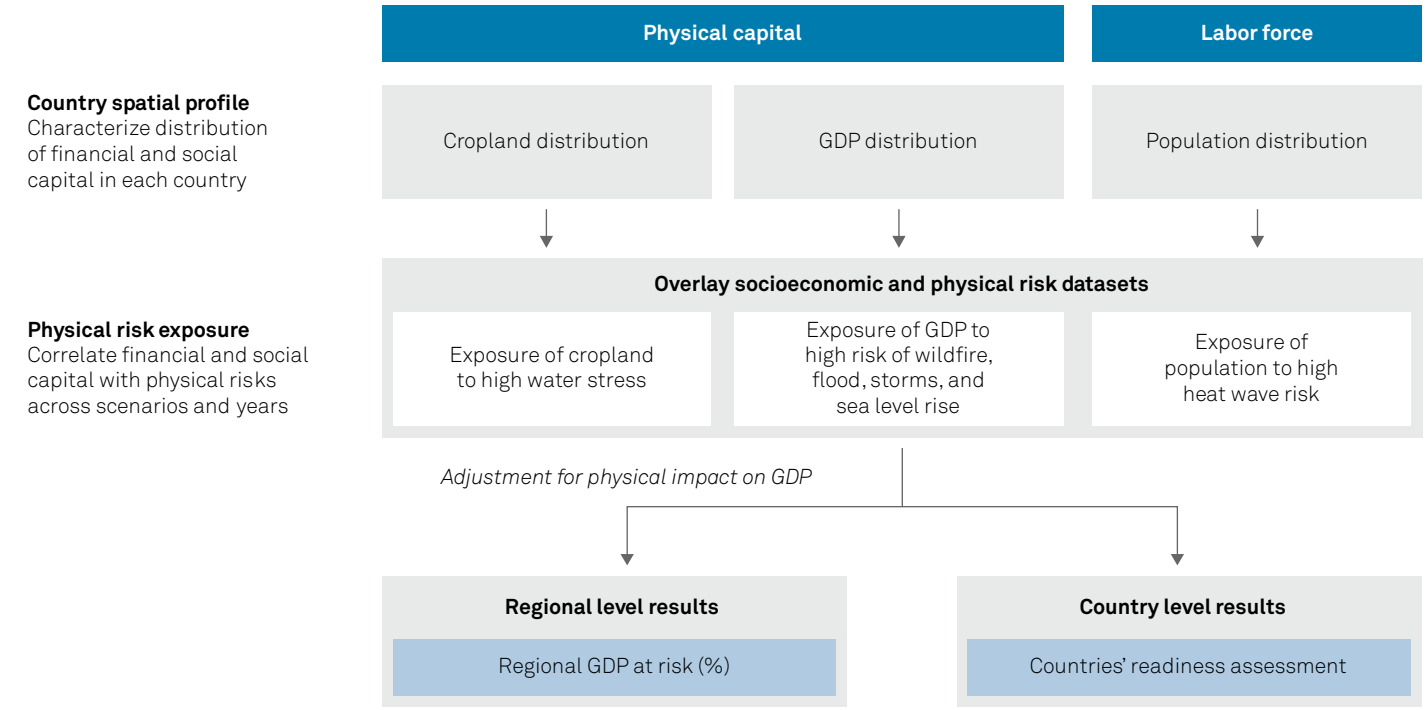
We assess the vulnerability of 135 countries within our rated universe to different climate hazards--heat waves, flooding, sea level rise, water stress, and wildfire--over the next 30 years, assessing countries' readiness to adapt (see chart 1). We also include storms, based on historical exposure due to uncertainty associated with change in this hazard over time. Our analysis starts with an assessment of exposure to climate hazards under multiple climate scenarios to 2050. We then look at two distinct components:

- Economic impact of climate hazards at the regional level.
  We combine the exposure and GDP loss estimates at a regional level to get an understanding of potential economic impacts of physical climate risks.
- Individual countries' readiness and capacity to adapt to physical climate risks.
  We map readiness to exposure at the country level to understand specific risks facing each country.

Each layer 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.

Chart 1

S&P Global Ratings' Approach For Assessing Sovereign Vulnerability To Physical Climate Risks



Note: Storms includes hurricanes, typhoons, and tropical cyclones. Source: S&P Global Ratings.

What Do The Exposure, GDP At Risk, And Readiness Assessment Metrics Mean?

Exposure

To various climate hazards quantifies the share of GDP or population likely to be affected by a high occurrence of chronic physical risks (that is, sea level rise and those manifesting over the medium to longer term, including changes to precipitation and temperature patterns) and acute physical risks (such as storms, water stress, heat waves, wildfire, and flooding) under the different RCP scenarios and time periods. It doesn't model the probability of the climate hazards occurring individually or jointly, which would be less than 1.

The regional combined GDP at risk metrics

Represent the expected share of GDP projected to be at risk of loss due to high exposure to a combination of chronic and acute physical risks under the different RCPs in a given year, absent any adaptation to climate risk and if all risks materialize simultaneously.

The readiness assessment

Provides a relative picture of countries' ability to avoid and respond to some of these losses based on their economic and institutional strength. We assess readiness on a scale of 1 to 6, from high to low, where a higher score points to lower capacity to adapt.

The Appendix displays these metrics for all 135 countries in our analysis.

Assessing the exposure to climate hazards

The exposure metric captures the geographic location of economic output (GDP distribution and agricultural land) and labor force (population distribution) within each country, overlaid with areas of high exposure to each climate hazard (see table 1) under different RCPs, including RCP2.6, RCP4.5, RCP8.5, and timepoints (baseline, 2030, and 2050). We use the S&P Global Trucost Physical Risk dataset. This data is derived from publicly available information, licensed datasets, and its own models.

Table 1

Thresholds For Each Climate Hazard

Climate Hazard	Threshold	Rationale
Water stress	BWS >=40	WRI definition of high risk
Heat wave	45 days	Six weeks or more of heat wave days per year
Wildfire	34+ score	Transition point from low to moderate or high risk
Flood	>1 score	Any level of flood exposure considered consequential for economic output
Coastal flood	>1 score	Any level of coastal flood exposure considered consequential for economic output
Hurricane/ Typhoon/Cyclone	>1 score	Any level of hurricane, typhoon, cyclone exposure considered consequential for economic output
Combined	As above	Exposure to physical risks above the threshold for any of the climate hazards noted above

BWS--Baseline water stress. WRI--World Resources Institute. Sources: S&P Global Ratings, S&P Global Sustainable1.

For the purpose of this analysis, 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 (see "Damage Limitation: Using Enhanced Physical Climate Risk Analytics In The U.S. CMBS Sector," Feb. 19, 2021). Note also that in our analysis, exposure to hurricanes, typhoons, or tropical storms--which we refer to hereafter as storms--is taken as present day (or more precisely, the historical average of storm events over the last few decades) because reliable projections for this particular hazard are unavailable. Note that the IPCC AR6 suggests

that the frequency of the most intense storms more likely than not will increase substantially in some ocean basins, while the number of storms could stay the same or decrease with climate change, illustrating the high uncertainty associated with such climate hazards.

Estimating The Economic Impact Of Climate Hazards At The Regional Level

We combine all of the expected GDP losses from climate hazards, modeled with our exposure metric, into a single metric. This measure captures the percentage of GDP at risk to be lost from physical climate risks for each region in a given year, but doesn't consider that some areas have adapted to those risks or will put mitigation measures in place to respond to these potential shocks.

Output impact estimates for drought, floods, and wind hazards are taken from Formetta and Feyen (2019). They use a similar spatial approach to ours to compute the loss rates associated with those hazards, which enables us to match our climate scenario modeling with appropriate loss rate estimates. Admittedly, the data is not very granular as estimates are only available for two income buckets of countries ("low-middle, low income" and "high-middle, high income" countries). Still, to our current knowledge this is the only study that uses a spatial analysis on a global scale to determine the losses associated with climate hazards.

For heat waves, since we focus on the population and not the area at risk, we find that labor productivity impact estimates from Roson and Sartori (2016) are more appropriate as a proxy of potential losses and can account for each countries' specific temperature. Those are available for 1°C to 5°C average warming for 140 locations and three sectors: agriculture, industry, and services. Where no country estimate is available, we used the GDP-weighted regional average. Using World Bank data, we then compute a sector GDP-weighted average of the labor productivity impact for each country in our analysis, to more accurately reflect countries' economic structure. We use the 1°C, 2°C, and 3°C estimates to match our low (RCP2.6), moderate (RCP4.5), and high (RCP8.5) scenarios, respectively.

Examining Countries' Readiness To Adapt To Physical Climate Risks

Countries with similar exposure to acute and chronic physical climate risks may differ in their capacity to manage and adapt to climate-related impacts. Economic resilience may vary greatly over geographic space and between countries, yet all sovereigns have the potential to build resilience to such events over time to meet new challenges and to take advantage of any opportunities that may emerge. Broadly speaking, an assessment of a country's preparedness to manage and adapt to climate risks complements the assessment of exposure.

In lieu of estimating GDP loss at the country level, we examine individual countries' readiness to adapt to physical climate risks, using S&P Global Rating's institutional and economic assessments as a starting point for our readiness indicator. These assessments, which we borrow from our sovereign credit rating methodology, can inform the institutional and financial capacity of countries to invest in adaptation and respond to physical climate risks.

Our economic assessment, anchored in GDP per capita, captures a country's level of economic development, which in turn offers an insight into its past and current ability to meet various policy challenges. It also reflects its 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.

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 worsening the economic assessment by one level to arrive at an adjusted measure of the sovereign's capacity to address the long-term impacts of physical 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 the risks arising from climate change and the energy transition, which in turn help to sustain long-term growth prospects.

If Countries Act On Their Current Pledges, GDP At Risk Of Losses From Physical Risks Could Still Rise To Around 4% Of GDP By 2050

Combining our physical risk exposure assessment and GDP loss estimates at the regional level, we find that in 2050, physical risks could expose:

- Around 4% of GDP to potential losses globally under current commitments that generally align to RCP4.5, a moderate climate scenario (see chart 2);
- Up to 4.5% of world GDP under a high stress (RCP8.5) scenario; and
- Around 3.3% of world GDP under a low stress (RCP2.6) scenario.

These risks and their associated costs are expected to increase over time as they are projected to become more frequent and severe, particularly from mid-century to 2100. That said, countries may be able to mitigate some of these losses depending on their readiness and capacity to adapt. (The following section dives deeper into our country-level analysis, as described earlier.)

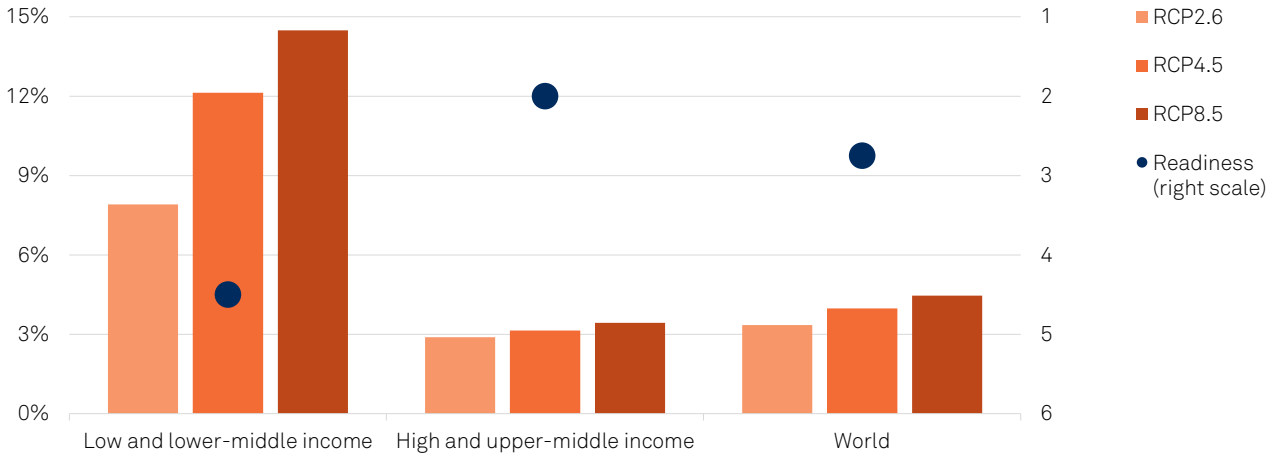
Acute risks like storms, floods, and wildfires are likely to prompt the greatest GDP losses. By contrast, most countries may be able to cope with heat waves, especially richer and more services-oriented economies. Heat waves have a smaller impact on labor productivity in the services sector than in agriculture, where workers are more exposed to outside conditions and heat.

However, countries' exposure to physical risks and their ability to respond to them varies. Countries located around the equator and small island states are typically highly vulnerable to climate change. Those geographic locations also tend to be home to less developed countries with less diversified economies. This positive correlation between higher exposure and lower economic development may result from the geographic determinant of economic development supported by Jared Diamond's theory (see "Guns, Germs, and Steel: The Fates of Human Societies," 1997). As a result, we find that climate hazards result in GDP losses that are on average 3.6 times greater for lower-income countries than their wealthier peers (see chart 2). These are likely to exacerbate their potential income losses, as they often lack the financial means and institutional strength to prepare and respond to these types of events compared with high- and upper-middle-income countries, which have a greater capacity to adapt. In an in-depth analysis, the IMF shows that temperature shocks hurt non-advanced economies, which are also often hotter, significantly more than their advanced peers (see IMF, 2017) and which have less insurance coverage.

Chart 2

Lower-Income Countries Are More At Risk Of Physical Climate Hazards In 2050

Combined GDP at risk (%) and readiness score



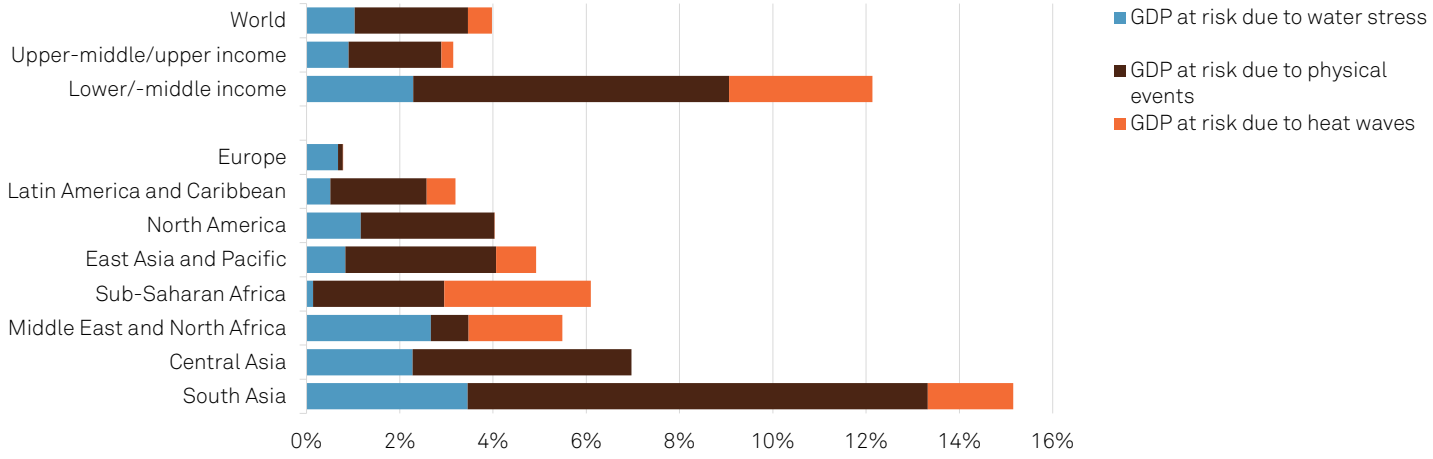
Note: Countries' income classification is based on World Bank data. Sources: S&P Global Ratings, S&P Global Sustainable1 (2022).

Regional results show South Asia is the most affected region, with physical climate risks likely to place around 15% of countries' GDP at risk by 2050, absent adaptation. It is 10 times more exposed than Europe, the least affected region (see chart 3). South Asian countries are particularly exposed to storms, floods, and sea level rise, though droughts and heat waves will also likely become more pronounced and frequent over time with climate change.

Chart 3

South Asia Is 10 Times More Exposed Than Europe

2050 combined GDP at risk under RCP4.5, physical risk contribution



Note: Countries' income and regional classification is based on World Bank. Sources: S&P Global Ratings, S&P Global Sustainable1 (2022).

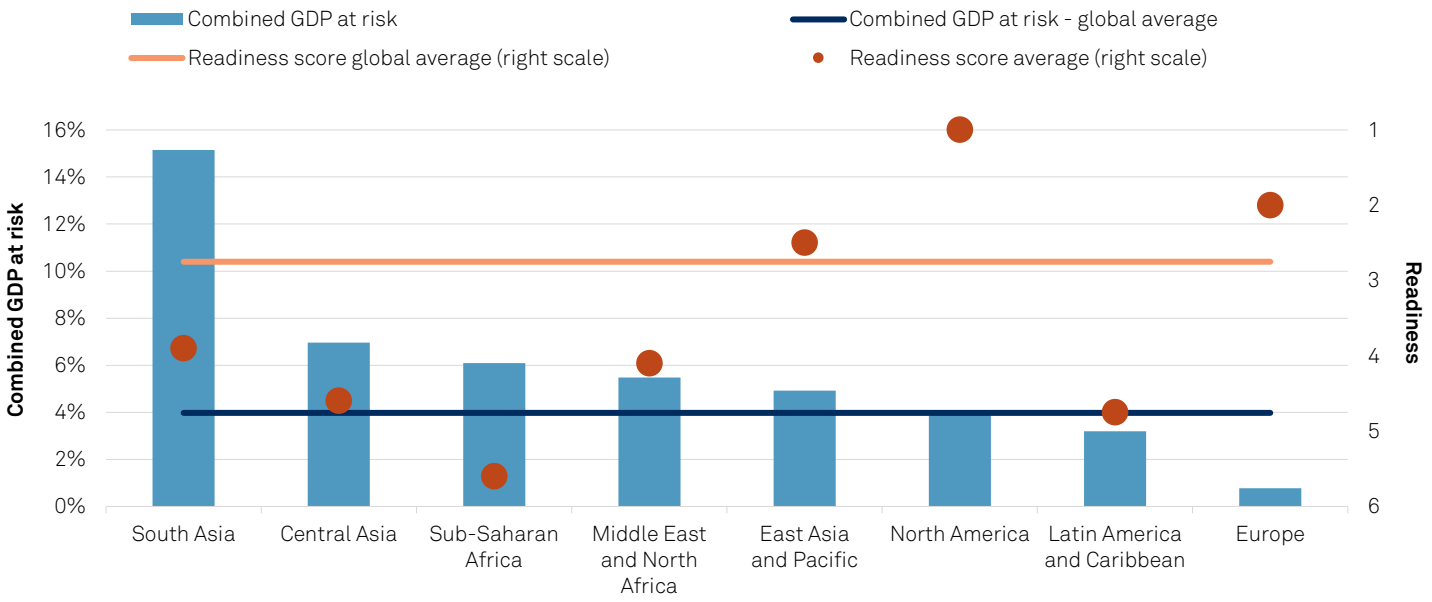
Countries in Central Asia, Sub-Saharan Africa, and the Middle East and North Africa (MENA) are likely to experience the second-highest GDP losses from physical risks out to 2050 in our analysis. Their exposure to damaging physical risks is around one-half that of South Asian countries, but overall readiness in MENA is lower (see chart 4). By contrast to Central Asia, MENA and Sub-Saharan Africa are likely to be much more affected by heat waves. Water stress is also set to become the main risk associated with climate change in MENA and the second one in Central Asia. This stands in contrast with Sub-Saharan Africa, which has the least agricultural land at risk of water stress in the world. While somewhat surprising, this is because arid land in that region is not currently used for agriculture purposes and other land features low to

moderate water stress (that is, below the high-risk threshold that we use to identify highly exposed areas; see table 1). Nonetheless, we view that Sub-Saharan countries are the least prepared to mitigate those risks (see chart 4). That's because most fall into the categories of lower- or middle-income countries, and therefore have fewer financial means, and typically have weaker institutions.

Chart 4

Sub-Saharan Countries Are The Least Prepared To Mitigate Physical Risks

Average combined GDP at risk and readiness for different global regions



Note: For our regional assessment, we complement our analysis with countries not part of our rated universe, using ND-GAIN's economic readiness metric as a proxy to get a more robust aggregate regional view of overall readiness. A lower readiness score means better readiness.
Sources: S&P Global Ratings, S&P Global Sustainable1 (2022).

Countries in the East Asia and Pacific region are expected to face similar levels of exposure as Sub-Saharan Africa, but mainly because of a high exposure to storms and floods (see chart 3). This region contains a large number of islands--for example, the Philippines and other East Asian islands--which are much more vulnerable to climate change (especially storms and sea level rise) than the rest of the world. To put this in context, we find that in the Latin America and Caribbean region, the Caribbean is exposed to similar physical risks as islands in the Pacific. That said, many countries in East Asia and Pacific are relatively more economically advanced--for example, Japan, Hong Kong, Singapore, and Australia--which makes the region much more likely to adapt to those risks than most of their Caribbean peers.

Outside of the Caribbean, physical climate risk exposure in Latin America is lower than in North America, where water stress is likely to become a greater issue than in South America (see chart 4). That said, the more affluent North is much better placed to respond to these risks--mostly owing to the strength of the U.S. economy, stable institutions, and a strong capacity to respond to crises in general, compared with the more volatile economic conditions and less market-friendly institutions in the southern part of the continent.

Finally, richer countries in Europe face the lowest GDP at risk. European countries have on average three times less GDP at risk than other global regions. This modest impact is the result of generally fewer damaging physical risks, such as storms, compared with other regions. That said, it remains to be seen how the effects of some chronic risks (such as sea level rise and long-term changes in temperature and precipitation) will play out in the region.

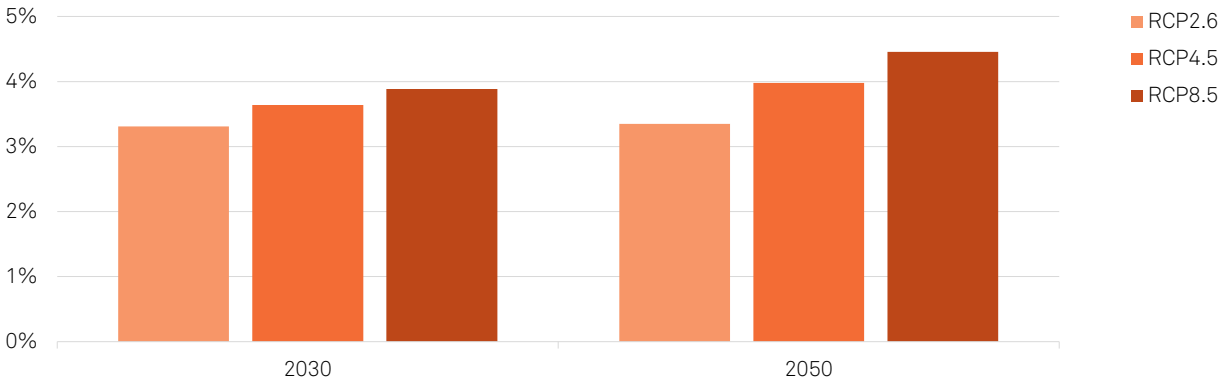
The Changing Nature Of Vulnerability: Alignment To The Paris Agreement Can Help Prevent Rising Losses

Our range of climate scenarios highlights that GDP losses linked to physical climate risks are likely to increase for most regions over time and in more dramatic warming pathways (see chart 5). Alignment to the Paris Agreement (that is, RCP2.6) could likely still prevent the world from seeing increasing losses linked to physical climate risks, with exposure expected to rise only by around 3%, compared with 17% and 23% in the RCP4.5 and RCP8.5 scenarios, respectively. Under the Paris Alignment scenario, a less pronounced pace of global warming would also give countries more time to adapt to harsher conditions. By contrast, as physical risks become more acute more quickly under RCP8.5, we estimate that it will be harder for countries to get ready--especially as more resources are likely to be needed to respond to more frequent and more damaging climate hazards--diverting financing away from potential investments and innovation toward acute risk mitigation.

Chart 5

Less Warming Is Better For Future Incomes Globally

Percentage of world GDP at risk under different climate change scenarios



Sources: S&P Global Ratings, S&P Global Sustainable1 (2022).

Meanwhile, even in this respect, countries stand to face unequal changes in exposure to climate hazards. Indeed, South Asia is not only the most affected region globally in our analysis, it's also the region expected to see the greatest increase in exposure until 2050, under RCP4.5, followed by Central Asia and Sub-Saharan Africa (see chart 6 and table 2). We expect that increasing exposure will likely materialize principally through more damaging physical risks and heat wave productivity-related impacts. At the regional level by contrast, Europe doesn't stand to see a large increase in GDP at risk of losses associated with climate hazards.

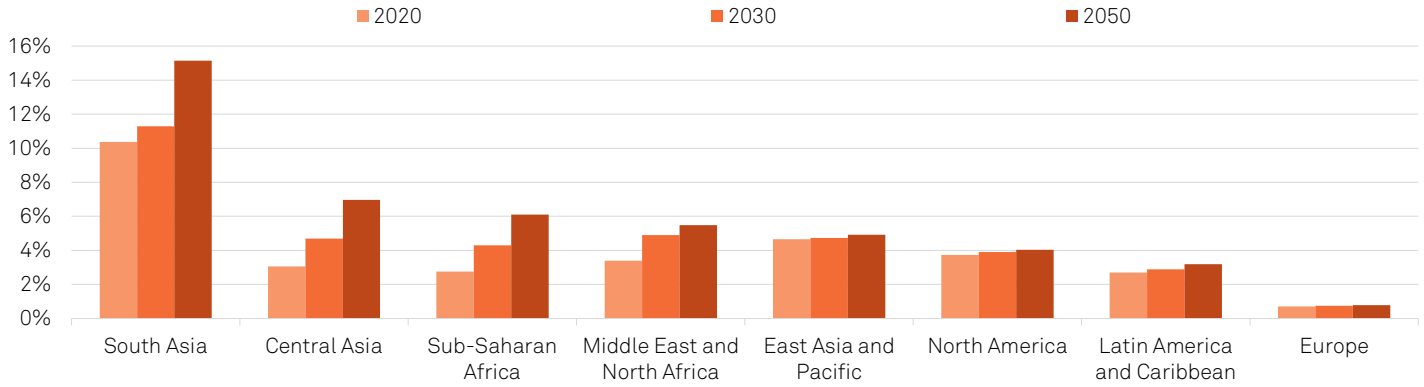
Our 2020 GDP at risk estimates highlight that a large part of the world is already exposed to climate hazards, in particular South Asian countries. However, the losses incurred so far have been much lower than our GDP at risk estimates. For example, in the U.S. and EU, losses have amounted to 0.6% and 0.1%, respectively, of GDP annually according to the National Centers for Environmental Information (NCEI) and the European Environment Agency (EEA), which corresponds to only around 16%-17% of our exposure numbers for 2020. There are three reasons that explain most of the gap:

- Our exposure estimates do not differentiate the probability of multiple climate hazards occurring at the same time;
- The areas identified as being exposed may not actually see impacts--extreme or acute events do not necessarily cause extreme impacts; and
- Our estimates also do not consider governments' and communities' adaptation efforts.

Chart 6

South Asia, Central Asia, And Sub-Saharan Africa Will See More Worsening Of Climate Conditions

Percentage of GDP at risk under RCP4.5



Note: Estimates for 2020 are not based on realized GDP losses. They reflect countries' GDP exposure to physical risks based on the thresholds defined in our climate scenario analysis, which don't model the probability that an event takes place. Sources: S&P Global Ratings, S&P Global Sustainable1 (2022).

Indeed, some of the affected areas may have adapted (at least in part) to those risks and can mitigate some of the losses that our GDP at risk estimates signal. By way of an example, 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, which correspond to 27% of our risk metric--significantly more than the EU or U.S., likely reflecting lower readiness to face those shocks. An even more extreme example is the Caribbean, which typically suffers damage losses associated with storms averaging 17% of their GDP, according to the UN Development Programme--twice as much as our GDP at risk metric suggests, reflecting the high impact of acute climate hazards. Finally, accounting for the probability of climate events occurring may suggest a greater increase in realized losses over the next 30 years as the mean of the probability distribution may increase and its tail may fatten (see IPCC 2018; 2022).

Table 2

Average Change In GDP At Risk Ranking From The Baseline

Using combined GDP at risk for global regions in 2050 under a moderate stress (RCP4.5) scenario*

Region	Average change in GDP at risk ranking between baseline and 2050
(Negative value = worsening rank)	
South Asia	-24
Sub-Saharan Africa	-18
Central Asia	-16
North America	-10
Middle East & North Africa	-2
East Asia & Pacific	2
Europe	11
Latin America & Caribbean	11

*GDP at risk to physical events, agriculture land at risk of water stress, and population exposure to heat waves. Note: Region classification based on World Bank data. Sources: S&P Global Ratings, S&P Global Sustainable1. Data as of March 14, 2022.

Chart 6 demonstrates that we expect exposure to increase in all regions as climate change will generally lead to more widespread and severe climate hazards. In addition, exposure to climate hazards is likely to increase as economic growth creates more wealth and goods to be damaged

or lost. Absent any adaptation or relocation of economic activity to less exposed areas, losses will also likely make up a greater proportion of countries' GDP.

The trajectory of future realized losses is less certain. It will be a function of growing exposure but also the likely increase of the probability of events occurring and how well countries are able to adapt and mitigate. An increase in the probability of multiple climate hazards occurring will also increase the amount of realized losses as exposure grows. However, climate science is not settled on whether and by what magnitude this increase in probability will occur for all climate hazards and geographies. Society's ability to improve resilience to the impacts of acute and chronic physical risks will likely help to dampen realized losses in the future.

There Is A Wide Divergence In Countries' Physical Risk Exposure And Capacity To Adapt

In this section, we take a closer look at physical risk exposure and readiness across individual countries. To this aim, we map our readiness assessment to the three different types of physical risk exposure modeled in our climate scenario for each country of our rated universe.

Key Takeaways

- Physical risks drive vulnerability of South Asian countries while heat waves will increase. Bangladesh and India are likely to have a greater share of their economies exposed to acute physical risks by 2050 under RCP4.5, but are assessed to be better prepared to face those risks within South Asia.
- Typhoons and sea level rise are projected to become particularly acute in East Asia and the Pacific Islands. Fiji, Hong Kong, Taiwan, and Papua Guinea will be particularly exposed to acute physical risks by midcentury, although readiness remains relatively high. China's exposure comes from water stress and acute physical risks, but the country is relatively well placed to adapt.
- Latin America and Caribbean see increasing vulnerability amid lower readiness. Caribbean islands and Central American countries are significantly more exposed in 2050 than other Latin American regional peers, with storms, sea level rise, and flooding primarily driving exposure.
- Heat waves will drive exposure of Sub-Saharan African countries. By 2050, 80% of countries in Sub-Saharan Africa are likely to have more than 45 days of heat waves per year, compared with less than 15% currently, coupled with more severe and frequent acute physical risks. Countries closer to the south pole are less affected, more so richer countries like South Africa and Botswana. Conflict and economic instability are likely to be exacerbated by the increased frequency of physical climate risks as those could weigh on available resources and spill over into adjacent regions.
- Middle East and North Africa face the greatest losses from water stress. Even though most MENA countries have limited exposure to the most damaging physical climate risks (excluding Bahrain and Iraq) in our analysis, our regional loss estimates suggest that the impacts from heat waves tend to lead to lower output losses than storms, floods, and wildfires because the vulnerability of most of the countries is high.
- Countries in Central Asia are among the most vulnerable. Central Asian countries are likely to be exposed to similar water stress levels as Mediterranean countries like Spain, Portugal, Italy, Greece, and Turkey. However, they are likely to experience greater impacts from these risks as a larger proportion of their GDP comes from agriculture.
- North America's and Europe's vulnerability is lower than other richer countries. Most EU countries have low GDP exposure to physical climate risks to 2050 under RCP4.5. Richer Western economies like Germany, the U.K., France, or Nordic economies could be among the best placed globally to adapt. The U.S. is the most exposed North American country to acute physical risks with 44% of GDP exposed to storms, wildfires, and flooding--ranking in the top half of countries globally in terms of exposure--but readiness to adapt is one of the highest in our assessment.

Note:

We report results of the RCP4.5 scenario in the sections that follow unless otherwise specified and focus on the raw physical exposure estimates and readiness assessment of countries in our rated universe (see charts 7-9). In each case, storm exposure is taken as baseline only due to uncertainty associated with forward-looking projections of this climate hazard.

The Appendix contains full results for all 135 countries included in our analysis, as well as limitations to our approach.

Charts 7-9 provide a clearer picture of where countries stand in the face of climate change. We expect that countries in the upper-right quadrant of the charts could face the greatest impacts from climate change, while those in the lower-left quadrant are likely to face more modest losses. For economies in the upper-left and lower-right quadrants, the picture is more mixed. However, we note that advanced economies that are highly exposed to physical climate risks--for example, Hong Kong and Singapore--are likely to mitigate a significant proportion of these

expected impacts and recover with greater ease than countries with weaker institutions and less prosperous economies. Countries in the lower-right quadrant (with low exposure and low readiness) may be vulnerable to unexpected acute risks like wildfire, storms and flooding, and worsening chronic risks, such as sea level rise and changing temperature and precipitation patterns.

Under A Moderate Stress (RCP4.5) Scenario And Readiness, 2050

Chart 7

GDP Exposure To Wildfire, Flood, Sea Level Rise, Or Storms*
Percentage of GDP

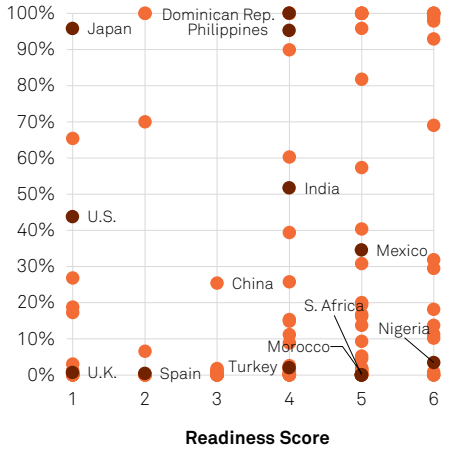


Chart 8

GDP Exposure To Agricultural land at risk of Water Stress
Percentage of GDP

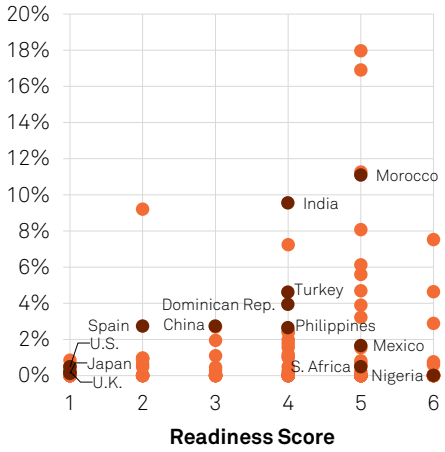
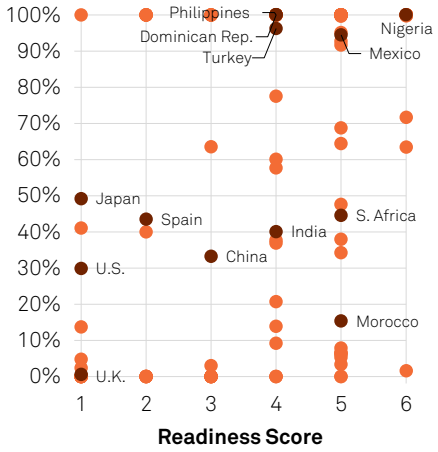


Chart 9

Population Exposure To Heat Waves
Percentage of population



Note: A lower readiness score means better readiness. *Storms exposure taken as baseline only. Sources: S&P Global Ratings, S&P Global Sustainable1 (2022).

Physical Risks Drive Vulnerability Of South Asian Countries While Heat Waves Will Increase

In South Asia, our analysis suggests that Bangladesh and India are likely to have a greater share of their economies exposed to physical risks than peers by 2050 (see table 3), as a result of high exposure to wildfire, floods, storms, and sea level rise. By contrast, agricultural water stress will affect Pakistan and Sri Lanka more.

Table 3

Countries In South Asia In 2050 Under A Moderate Stress (RCP4.5) Scenario

Percentage of GDP exposure to one or more physical risks, agricultural land to water stress, and population exposure to heat waves

Sovereign	Readiness assessment	Total GDP exposure (wildfire, flood, sea level rise or storms)	GDP exposure based on agricultural land at risk of water stress	Agricultural land exposed to water stress	Population exposure (heat waves)
Bangladesh	4	90%	0%	0%	21%
India	4	52%	10%	62%	40%
Pakistan	5	20%	17%	81%	48%
Sri Lanka	5	5%	5%	73%	100%

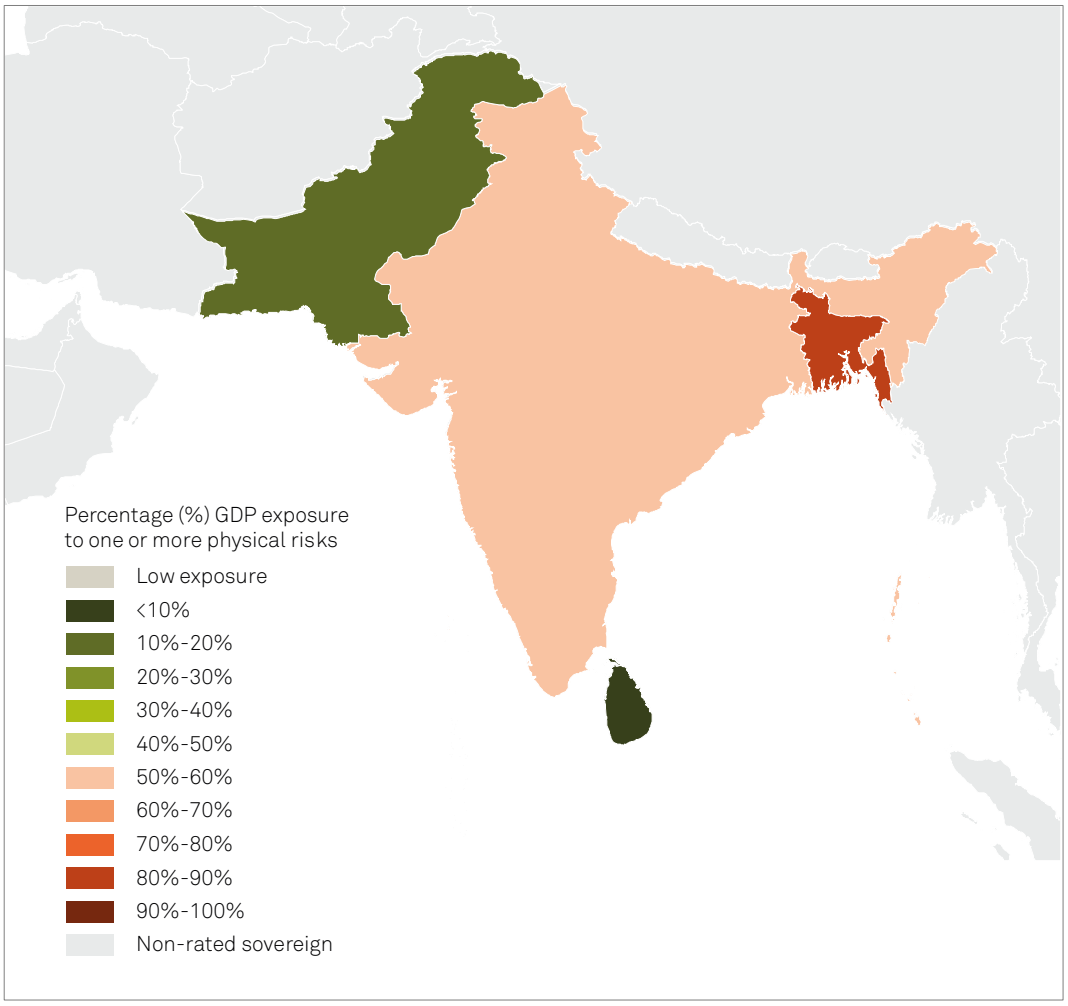
Note: Wildfire, flood, sea level rise, or storms--storms exposure taken as baseline only. Region classification based on World Bank data. Data sorted by greatest exposure to acute physical risks (column 3: high to low).

Readiness of South Asian countries is also in the medium to lower part of the range. India and Bangladesh are assessed to be better prepared to face those risks owing to stronger economies and institutions.

Chart 10

Countries In South Asia In 2050 Under A Moderate Stress (RCP4.5) Scenario

Total GDP Exposure To Wildfire, Flood, Sea Level Rise, Or Storms (%)



Note: Physical risks comprise wildfire, flood, sea level rise, or storms--storms exposure taken as baseline only. Sources: S&P Global Ratings, S&P Global Sustainable1 (2022).

Typhoons And Sea Level Rise Will Become Particularly Acute In East Asia And For Pacific Islands

Our scenario analysis highlights that the East Asia and Pacific rated entities of Fiji, Hong Kong, Taiwan, and Papua Guinea as likely to be particularly exposed to tropical storms and cyclones, floods, sea level rise, and heat waves by 2050. However, notwithstanding similar exposure, Hong Kong and Taiwan are better placed to adapt to such risks thanks to their economies' strength and institutions (see table 4).

For China, the majority of the country's exposure is likely to come from damaging weather events, like storms and flooding, as well as sea level rise and population exposure to heat waves. That said, China is relatively well placed to mitigate such damage with a readiness assessment of 3. Meanwhile, wildfires, floods, storms, and sea level rise predominantly drive the exposure of Australia in 2050.

Table 4

Rated Entities In East Asia And Pacific In 2050 Under A Moderate Stress (RCP4.5) Scenario

Percentage of GDP exposure to one or more physical risks, agricultural land to water stress, and population exposure to heat waves

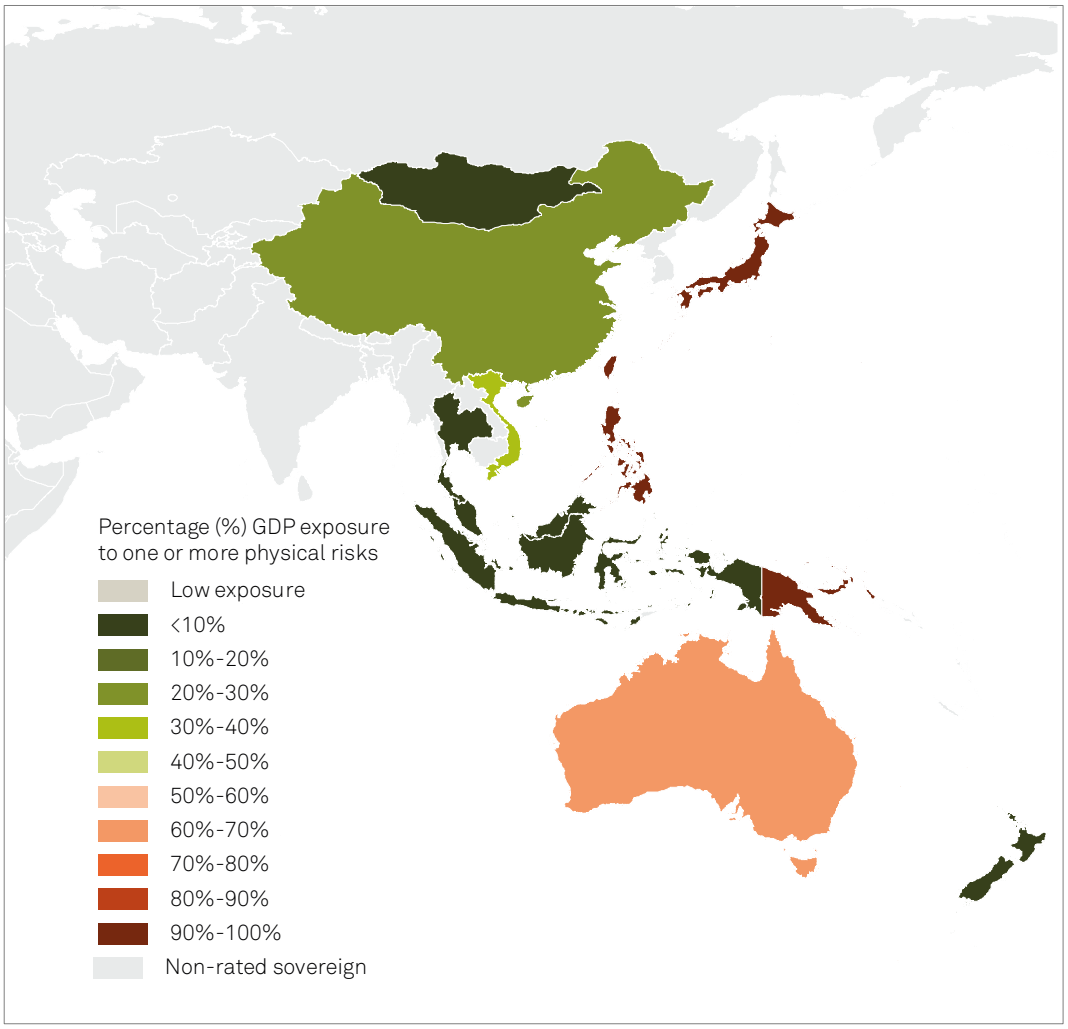
Rated entities	Readiness assessment (1-6)	Total GDP exposure (wildfire, flood, sea level rise or storms)	GDP exposure based on agricultural land at risk of water stress	Agricultural land exposed to water stress	Population exposure (heat waves)
Fiji	5	100%	0%	0%	100%
Hong Kong	2	100%	0%	0%	100%
Papua New Guinea	6	100%	0%	0%	100%
Taiwan	2	100%	1%	11%	100%
Japan	1	96%	0%	14%	49%
Philippines	4	95%	3%	35%	100%
Republic of Korea (South Korea)	2	70%	0%	28%	40%
Australia	1	65%	1%	42%	5%
Vietnam	4	39%	0%	4%	60%
China	3	25%	3%	49%	33%
Singapore	1	17%	0%	0%	100%
Thailand	4	9%	0%	0%	58%
Indonesia	4	2%	1%	9%	100%
Malaysia	4	2%	0%	4%	100%
Mongolia	4	0%	2%	22%	0%
New Zealand	1	0%	0%	0%	41%
Cook Islands	4	0%	0%	0%	100%

Note: Wildfire, flood, sea level rise, or storms--storms exposure taken as baseline only. Region classification based on World Bank data. Data sorted by greatest exposure to physical risks (column 3: high to low).

Many Pacific island states, including Papua New Guinea and the Philippines, face similar proportions of exposure to physical risks--in each case, our analysis suggests that damaging risks, like wildfires, storms, flooding, and sea level rise, contribute, on average, to the vast majority of this risk.

Chart 11

Countries In East Asia & Pacific In 2050 Under A Moderate Stress (RCP4.5) Scenario Total GDP Exposure To Wildfire, Flood, Sea Level Rise, Or Storms (%)



Note: Physical risks comprise wildfire, flood, sea level rise, or storms--storms exposure taken as baseline only. Sources: S&P Global Ratings, S&P Global Sustainable1 (2022).

Latin America And Caribbean See Increasing Vulnerability Amid Lower Readiness

Caribbean islands--including Aruba, Bahamas, Barbados, and others--and Central American countries--for example, Nicaragua and Honduras--are significantly more exposed in 2050 than other Latin American regional peers (see table 5). Damaging storms, wildfires, sea level rise, and flooding are the main drivers of exposure in these countries, though heat waves are also likely to affect the entire population in most countries. The impact of these climate hazards could be significant as on average these countries' readiness to adapt to physical climate risks is relatively low in our assessment (with readiness assessments closer to 5 or 6). In the past, similar damaging events, including storms, have taken a big toll on the economies of these small islands that are heavily reliant on tourism. Indeed, tourism made up around 44% of Aruba's GDP, 20% for the Bahamas, and 18% for Barbados in 2020. Richer economies like the Bahamas and the Turks and Caicos islands are somewhat better placed to mitigate the physical impacts of climate change.

Table 5

Rated Entities In Latin America And Caribbean In 2050 Under A Moderate Stress (RCP4.5) Scenario

Percentage of GDP exposure to one or more physical risks, agricultural land to water stress, and population exposure to heat waves

Rated entities	Readiness assessment	Total GDP exposure (wildfire, flood, sea level rise or storms)	GDP exposure based on agricultural land at risk of water stress	Agricultural land exposed to water stress	Population exposure (heat waves)
Aruba	5	100%	0%	0%	100%
Bahamas	4	100%	0%	0%	100%
Barbados	5	100%	0%	0%	100%
Belize	6	100%	0%	0%	100%
Curacao	5	100%	0%	0%	100%
Dominican Republic	4	100%	4%	84%	100%
Jamaica	6	100%	0%	0%	100%
Suriname	6	100%	0%	0%	100%
Trinidad and Tobago	5	100%	0%	0%	100%
Turks and Caicos Islands	4	100%	0%	0%	100%
Nicaragua	6	98%	0%	0%	100%
Honduras	5	96%	0%	0%	100%
Guatemala	6	69%	0%	0%	100%
Chile	4	60%	2%	50%	9%
El Salvador	5	57%	0%	0%	100%
Mexico	5	35%	2%	61%	94%
Argentina	5	17%	1%	11%	6%
Costa Rica	4	15%	0%	0%	100%
Bolivia	5	14%	0%	2%	100%
Peru	4	11%	1%	17%	100%
Brazil	5	9%	0%	0%	64%
Colombia	4	3%	0%	0%	100%
Panama	3	2%	0%	0%	100%
Paraguay	5	1%	0%	0%	6%
Uruguay	3	1%	0%	0%	0%
Ecuador	5	0%	1%	10%	100%
Falkland Islands	2	0%	0%	0%	0%
Montserrat	5	0%	0%	0%	100%

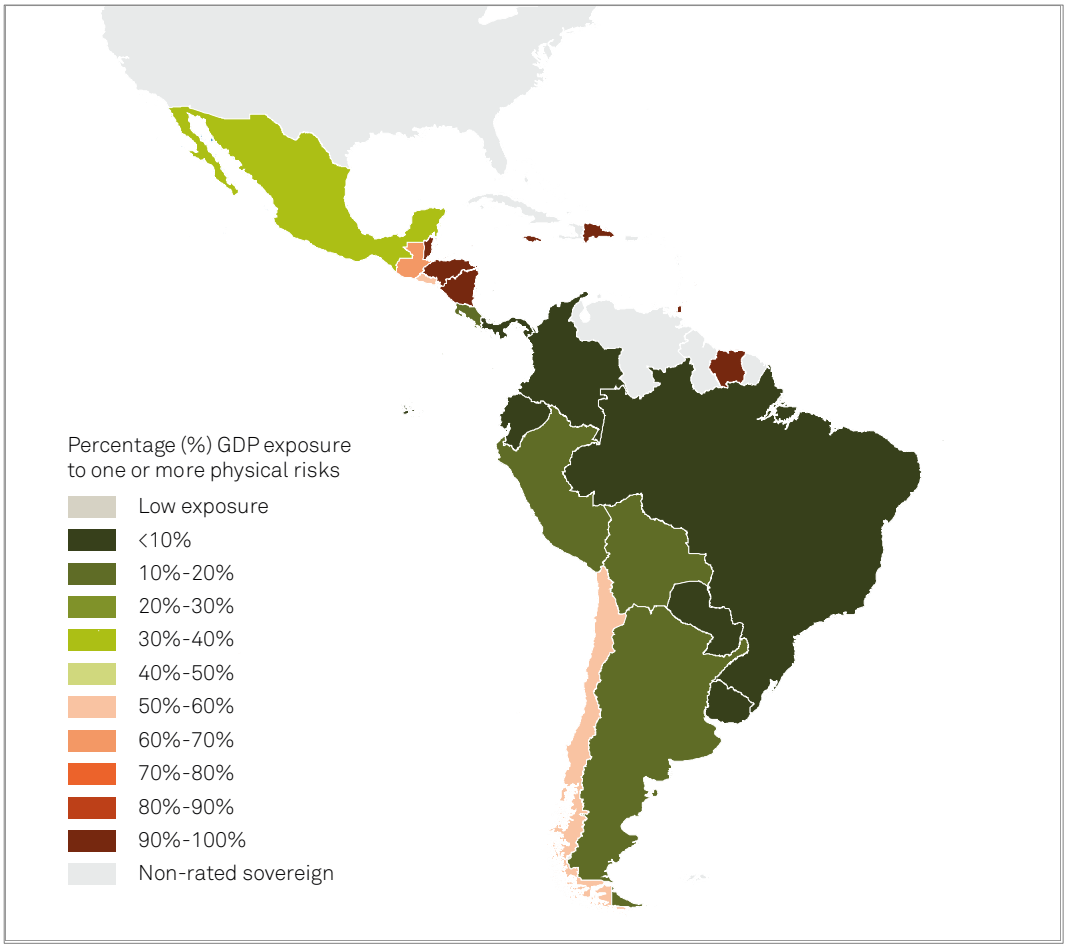
*Wildfire, flood, sea level rise, or storms. Note: Region classification based on World Bank data. Data sorted by greatest exposure to physical risks (column 3: high to low). Storms exposure taken as baseline only.

Lower readiness more generally in Latin America and Caribbean is reflected in our readiness assessment for countries in the region. We note a great disparity between readiness for the Caribbean islands and the rest of Latin America (see chart 12). The islands are likely to be much more affected by physical risks--like storms and sea level rise--similarly to Pacific islands. We expect that heat waves will also grow in prominence in the southern part of the region, but exposure to physical risks could be much lower in countries south of the equator and even Mexico.

Chart 12

Countries In Latin America And Caribbean In 2050 Under A Moderate Stress (RCP4.5) Scenario

Total GDP Exposure To Wildfire, Flood, Sea Level Rise, Or Storms (%)



Note: Physical risks comprise wildfire, flood, sea level rise, or storms--storms exposure taken as baseline only. Sources: S&P Global Ratings, S&P Global Sustainable1 (2022).

Heat Waves Will Drive Exposure Of Sub-Saharan African Countries

Sub-Saharan African countries are particularly exposed to physical climate risks, which we expect to mainly materialize in the form of heat waves. In our analysis, 80% of countries in Sub-Saharan Africa could have more than 45 days of heat waves per year by 2050, compared with less than 15% currently, coupled with more damaging and frequent physical risks.

Table 6

Rated Entities In Sub-Saharan Africa In 2050 Under A Moderate Scenario (RCP4.5)

Percentage (%) GDP exposure to one or more physical risks*, agricultural land to water stress, and population exposure to heat waves

Rated entities	Readiness assessment	Total GDP exposure (wildfire, flood, sea level rise or storms)	GDP exposure based on agricultural land at risk of water stress	Agricultural land exposed to water stress	Population exposure (heat waves)
Cape Verde	5	100%	0%	0%	100%
Burkina Faso	6	99%	0%	0%	100%
Ethiopia	6	93%	1%	2%	100%
Cameroon	5	40%	0%	0%	100%
Togo	6	32%	0%	0%	100%
Benin	5	31%	0%	0%	100%
Senegal	4	26%	0%	0%	100%
Botswana	5	19%	0%	0%	69%
Democratic Republic of the Congo	6	18%	0%	0%	100%
Ghana	5	16%	0%	0%	100%
Mozambique	6	14%	0%	0%	63%
Congo-Brazzaville	6	11%	0%	0%	100%
Zambia	6	10%	0%	0%	72%
Nigeria	6	3%	0%	0%	100%
Cote d'Ivoire	4	2%	0%	0%	100%
Kenya	5	2%	0%	0%	100%
Angola	6	1%	0%	0%	100%
South Africa	5	0%	1%	27%	45%
Uganda	6	0%	0%	0%	100%
Rwanda	5	0%	0%	0%	100%

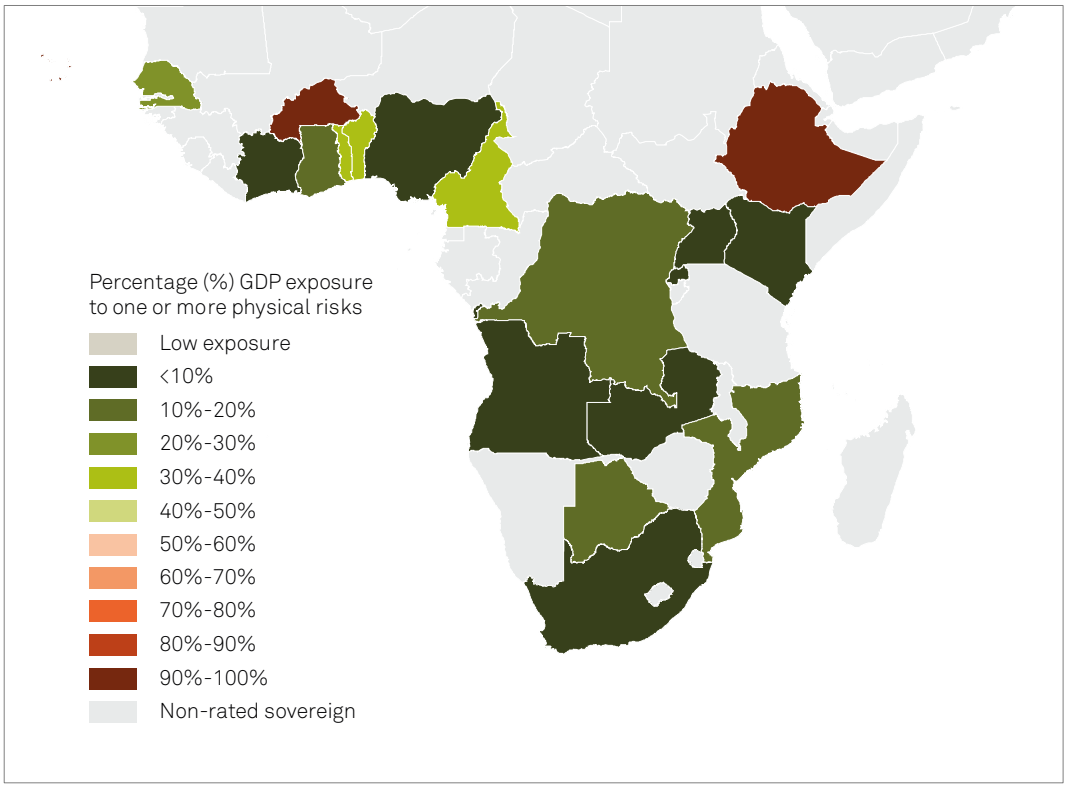
*Wildfire, flood, sea level rise, or storms. Note: Region classification based on World Bank data. Data sorted by greatest exposure to physical risks (column 3: high to low). Storms exposure taken as baseline only.

That said, the region will also see a large disparity in exposure. The most affected countries are located around the equator--including but not limited to Burkina Faso, Cape Verde, Ethiopia, Cameroon, Togo, and Benin--while countries closer to the south pole are less affected, especially upper-income countries like South Africa or Botswana. Aside from the deterministic geographical factors, our readiness assessments also highlight that most Sub-Saharan countries are less well equipped to prepare and respond to the physical impacts of climate change. Senegal and Cote d'Ivoire, which have greater readiness in our assessment, still place in the lower-middle range of our rated universe with a readiness assessment of 4. Many countries in Sub-Saharan Africa are prone to conflict and economic instability, which will likely be exacerbated by the increased occurrence of physical climate risks, as those could weigh on available resources and spill over into adjacent regions.

Chart 13

Countries In Sub-Saharan Africa In 2050 Under A Moderate Stress (RCP4.5) Scenario

Total GDP Exposure To Wildfire, Flood, Sea Level Rise, Or Storms (%)



Note: Physical risks comprise wildfire, flood, sea level rise, or storms--storms exposure taken as baseline only. Sources: S&P Global Ratings, S&P Global Sustainable1 (2022).

MENA Faces The Greatest Exposure To Water Stress

Unsurprisingly, the Middle East and North Africa is one of the most impacted by heat waves, along with Sub-Saharan Africa, but the region is more exposed to droughts than anywhere else in the world. Morocco, for example, is likely to see around 11% of GDP exposed to impacts from water stress linked to the high share of agriculture in the economy. Meanwhile, Bahrain has significantly greater exposure to damaging physical risks in this region (100% of the country's exposure), followed by Iraq, with 29% of GDP that could be exposed to such risks (see table 7).

Overall, even though most MENA countries have limited exposure to the most damaging physical climate risks (excluding Bahrain and Iraq), our regional loss estimates suggest that the impacts from heat waves tend to lead to lower output losses than storms, floods, and wildfires--most MENA countries' vulnerability remains high. In this region, countries' readiness assessments varies substantially ranging from 6 to 2. Although richer countries in this region--such as Israel, Qatar, the United Arab Emirates, Kuwait, and Malta--appear to have better readiness to deal with those risks today, we note that oil exporters could see their revenues decrease with the energy transition if their economies don't become more diverse, which could make them less well placed to cope with the physical impacts of climate change (see "The Energy Transition: The Clock Is Ticking For Middle East Hydrocarbon Exporters," published Feb. 16, 2020). Elsewhere in the region, readiness is weaker due to weaker economies and institutions (for example, Iraq, Lebanon, and Jordan).

Table 7

Rated Entities In Middle East & North Africa (MENA) In 2050 Under A Moderate Scenario (RCP4.5)

Percentage of GDP exposure to one or more physical risks, agricultural land to water stress, and population exposure to heat waves

Rated entities	Readiness assessment	Total GDP exposure (wildfire, flood, sea level rise or storms)	GDP exposure based on agricultural land at risk of water stress	Agricultural land exposed to water stress	Population exposure (heat waves)
Bahrain	4	100%	0%	0%	100%
Iraq	6	29%	1%	90%	100%
Oman	5	5%	2%	88%	92%
Egypt	5	2%	3%	33%	93%
Morocco	5	1%	11%	95%	15%
Kuwait	3	0%	0%	100%	100%
Saudi Arabia	4	0%	2%	99%	100%
Israel	2	0%	1%	99%	100%
Jordan	6	0%	5%	100%	100%
Lebanon	6	0%	3%	97%	100%
Malta	3	0%	0%	0%	100%
Qatar	2	0%	0%	0%	100%

Note: Wildfire, flood, sea level rise, or storms--storms exposure taken as baseline only. Region classification based on World Bank data. Data sorted by greatest exposure to physical risks (column 3: high to low).

Countries In Central Asia Are Among The Most Vulnerable

Central Asian countries are likely to be exposed to similar water stress levels as Mediterranean countries like Spain, Portugal, Italy, Greece, and Turkey. However, they are likely to experience greater impacts from these risks as a larger proportion of their GDP comes from agriculture. For example, 18% of Uzbekistan's GDP could be affected by water stress directly, due to the importance of the agricultural sector (see table 8). Meanwhile, our readiness assessment suggests they are likely to be less ready to respond to droughts than their richer Western European and East Asia and Pacific peers. Compounding this exposure, our analysis shows that Tajikistan and Uzbekistan are also highly exposed to physical climate risks within their region.

Table 8

Countries In Central Asia In 2050 Under A Moderate Stress (RCP4.5) Scenario

Percentage of GDP exposure to one or more physical risks, agricultural land to water stress, and population exposure to heat waves

Sovereign	Readiness assessment	Total GDP exposure (wildfire, flood, sea level rise or storms)	GDP exposure based on agricultural land at risk of water stress	Agricultural land exposed to water stress	Population exposure (heat waves)
Tajikistan	6	100%	8%	39%	2%
Uzbekistan	5	82%	18%	77%	0%
Kazakhstan	4	15%	2%	62%	0%

Note: Wildfire, flood, sea level rise, or storms--storms exposure taken as baseline only. Region classification based on World Bank data. Data sorted by greatest exposure to physical risks (column 3: high to low).

North America's And Europe's Vulnerability Is Lower For Richer Countries

By contrast, our analysis suggests that most EU countries have negligible GDP exposure to physical climate risks to 2050 under a moderate climate scenario (RCP4.5). Fewer damaging physical climate risks are projected to occur in the region, and heat waves will likely have limited impact on overall labor productivity in these largely services-based economies, where the overall temperature increase is also lower than countries more at risk of heat waves (see chart 14).

Of the larger EU countries, Portugal, Greece, and Spain are likely to be the most exposed to water stress risks (see table 9). We also note that the Netherlands is most exposed to flooding in the region, with 19% of its GDP set to be exposed to physical risks. That said, the country's current vast flood defenses (not captured in our analysis) should withstand most flood risk out to 2050. Heat waves are expected to become more pronounced, especially in Mediterranean economies and countries of similar latitude (such as Turkey), while northern European countries have comparatively limited exposure to physical climate risks, according to our scenario analysis. Nonetheless, as the impacts of chronic hazards, like sea level rise and changing temperature and precipitation patterns, play out over longer timescales, we expect the impacts to become more prevalent after the midcentury, absent adaptation.

Within Europe as a broader region, we assess readiness to mitigate those risks as relatively high in global comparison with an average readiness assessment of 2. That said, this hides some disparity across countries given a broad range of levels of economic development and institutional strength. While we believe that richer Western economies like Germany, the U.K., France, or Nordic economies are among the best-placed globally to adapt and mitigate these risks, countries outside the EU are likely to be relatively less prepared.

Table 9

Rated Entities In Europe In 2050 Under A Moderate Stress (RCP4.5) Scenario

Percentage (%) GDP exposure to one or more physical risks, agricultural land to water stress, and population exposure to heat waves

Rated entities	Readiness assessment	Total GDP exposure (wildfire, flood, sea level rise or storms)	GDP exposure based on agricultural land at risk of water stress	Agricultural land exposed to water stress	Population exposure (heat waves)
Armenia	5	0%	11%	96%	7%
Andorra	2	0%	9%	96%	0%
Albania	5	0%	8%	42%	100%
Macedonia	4	0%	7%	90%	100%
Azerbaijan	5	0%	6%	99%	3%
Ukraine	5	1%	6%	60%	8%
Turkey	4	2%	5%	83%	96%
Georgia	5	0%	4%	54%	34%
Spain	2	0%	3%	92%	43%
Greece	3	0%	3%	66%	100%
Portugal	3	1%	2%	96%	3%
Bulgaria	4	1%	2%	51%	78%
Italy	3	0%	1%	57%	64%
Romania	4	0%	1%	27%	37%
Belgium	2	0%	1%	94%	0%
Netherlands	1	19%	1%	27%	0%
France	1	1%	0%	24%	14%

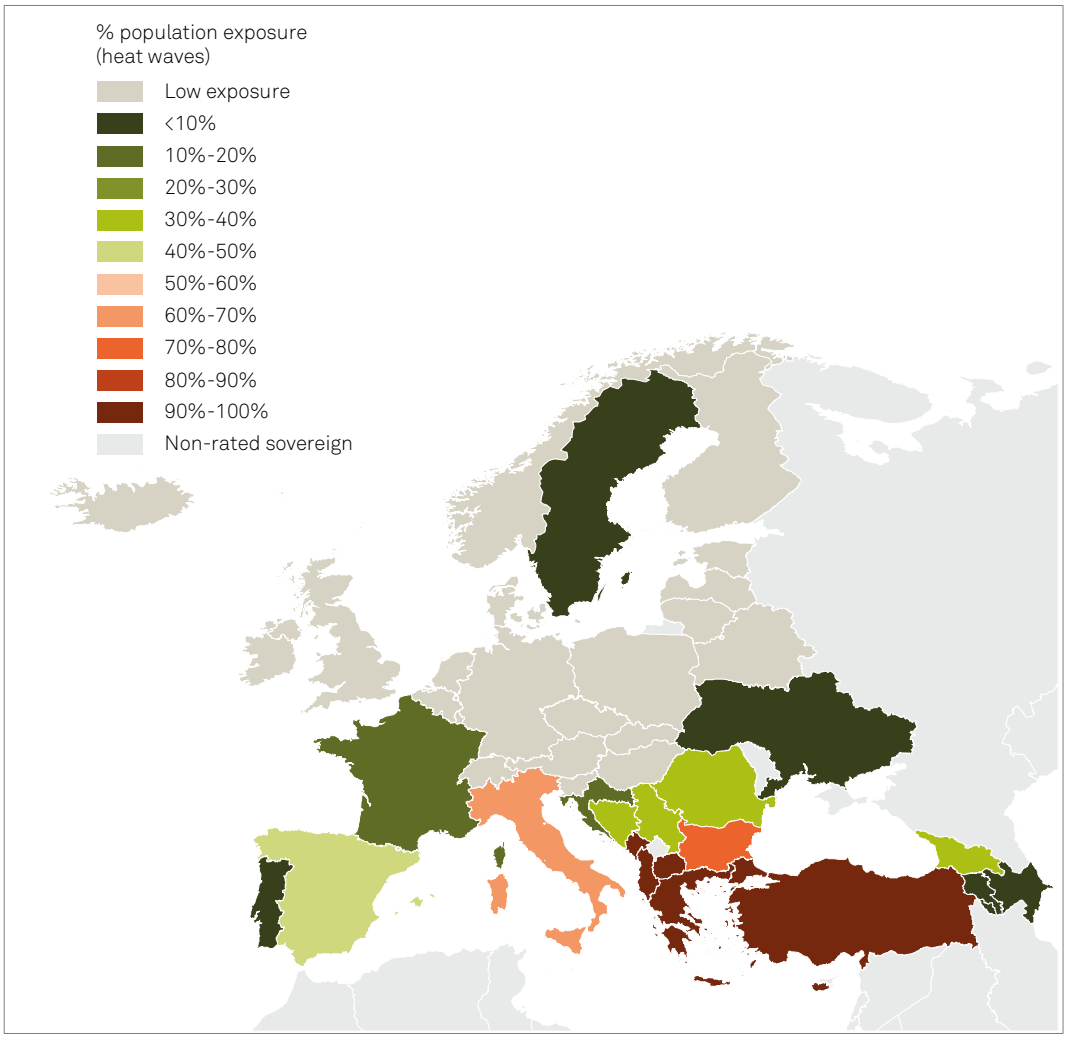
Russia	5	1%	0%	17%	5%
Hungary	3	0%	0%	16%	0%
Estonia	3	0%	0%	13%	0%
U.K.	1	1%	0%	23%	0%
Germany	1	1%	0%	12%	0%
Serbia	4	1%	0%	2%	38%
Lithuania	3	0%	0%	2%	0%
Latvia	3	0%	0%	1%	0%
Belarus	5	0%	0%	0%	0%
Poland	4	0%	0%	0%	0%
Ireland	1	0%	0%	1%	0%
Sweden	1	0%	0%	1%	1%
Czech Republic	3	0%	0%	0%	0%
Finland	1	0%	0%	0%	0%
Austria	1	3%	0%	0%	0%
Cyprus	3	1%	0%	0%	100%
Switzerland	1	0%	0%	0%	0%
Norway	1	0%	0%	0%	0%
Iceland	2	0%	0%	0%	0%
Croatia	4	0%	0%	0%	14%
Denmark	1	0%	0%	0%	0%
Bosnia and Herzegovina	5	0%	0%	0%	38%
Montenegro	4	0%	0%	0%	100%
Guernsey	2	0%	0%	0%	0%
Jersey	2	0%	0%	0%	0%
Liechtenstein	1	0%	0%	0%	0%
Luxembourg	1	0%	0%	4%	0%
Slovakia	3	0%	0%	0%	0%
Slovenia	3	0%	0%	0%	0%

Note: Wildfire, flood, sea level rise, or storms--storms exposure taken as baseline only. Region classification based on World Bank data. Data sorted by greatest exposure to physical risks (column 3: high to low).

Chart 14

Countries In Europe In 2050 Under A Moderate Stress (RCP4.5) Scenario

Percentage population exposure to heat waves (%)



Sources: S&P Global Ratings, S&P Global Sustainable1 (2022).

Finally, in North America, our analysis suggests that the U.S. is the most exposed country in the region to physical risks (see table 10). With 44% of its GDP likely to be exposed to storms, wildfires, sea level rise, and floods, the U.S. ranks in the top half of countries globally in terms of exposure in our analysis. It is also expected to see a much higher occurrence of heat waves, with 30% of its population likely to be exposed to heat waves out to 2050. Similarly to richer European countries, U.S. labor productivity impacts from heat waves are likely to be limited on aggregate. Yet, the impact may vary more widely in subregions with significant numbers of outdoor workers (that is, agriculture, forestry, or construction). Indeed, recent research highlighted that about 60% of outdoor workers could experience at least one week when extreme heat makes it too dangerous to work if little to no action is taken, equivalent to about $1,900 in income annually by midcentury as a result of extreme heat (Dahl and Licker, 2021). That said, the U.S. may be the country best placed to adapt to the impacts of heat waves according to our readiness assessment--reflecting a strong economy and flexible product and labor markets, as well as strong institutional structures.

Table 10

Rated Entities In North America In 2050 Under A Moderate Scenario (RCP4.5)

Percentage of GDP exposure to one or more physical risks, agricultural land to water stress, and population exposure to heat waves

Rated entities	Readiness assessment	Total GDP exposure (wildfire, flood, sea level rise or storms)	GDP exposure based on agricultural land at risk of water stress	Agricultural land exposed to water stress	Population exposure (heat waves)
U.S.	1	44%	0%	51%	30%
Canada	1	27%	0%	37%	2%
Bermuda	2	0%	0%	0%	100%

Note: Wildfire, flood, sea level rise, or storms--storms exposure taken as baseline only. Region classification based on World Bank data. Data sorted by greatest exposure to physical risks (column 3: high to low).

Although wealthier countries might be better equipped to deal with physical risks--thanks to diversified economic structures and ample financial means to prepare and rebuild--we note that the aggregate results are likely to overshadow more pronounced sectoral or regional losses. Indeed, our recent research on, for example, U.S. investor-owned utilities, U.S. commercial mortgage-backed securities (CMBS) and U.S. public finance (see the Related Research at the end of this article) reveals geographic patterns of exposure that emerge at the county and asset levels. For example, we found that over 38% of U.S. counties could face water scarcity risk in 2050 under a high stress (RCP8.5) climate scenario (see "Better Data Can Highlight Climate Exposure: Focus On U.S. Public Finance," Aug. 24, 2020) and that, 99% of the highly exposed properties backing U.S. CMBS transactions that we rate are spread across 10 states, with California concentrating most of the risk (see "Damage Limitation: Using Enhanced Physical Climate Risk Analytics In The U.S. CMBS Sector," Feb. 19, 2021).

Climate Finance Is Needed To Help Build Resilience Of Developing Countries To Climate Change To Which They Have Contributed Relatively Little

For most countries, exposure to the physical impacts of climate change is increasing with each passing year. At the same time, unraveling the transmission pathways that may place countries' economies at greater exposure to physical risks is not without challenges. This research is S&P Global Ratings' first assessment of countries' exposure and ability to cope with, and adapt to, climate change. The scenario analysis highlights that economic losses resulting from climate change are unevenly distributed across the globe. They will stem from various sources and will likely increase over time, likely more so if alignment to the Paris Agreement is not achieved. Understanding this context highlights the need for countries to implement their adaptation plans and the need for a better understanding about the potential knock-on effects of physical climate risks on economies. As such, some of our future work will focus on identifying the dynamic response of economies to these new challenges. More work is also needed to understand the probability of climate hazards events occurring, which would strengthen our scenario analysis.

Although some progress has been made to improve countries' resilience to the physical impacts of climate change, particularly through the Paris Agreement and National Adaptation Plans, more progress is clearly needed in many cases. Evidence so far points to a bigger adaptation gap for low-income developing economies, with the effect of temperature shocks having remained constant over time (see IMF, 2017). Looking forward, our analysis highlights that climate change will have disproportionally more adverse consequences for countries with lower readiness assessments--that is, with weaker institutions and fewer financial resources to cope. UNEP estimates that adaptation costs for low-income countries will increase from $140 billion-$300

billion per year by 2030 to $280 billion-$500 billion per year by 2050. International cooperation and support--such as the $100 billion per year by 2020 pledged by developed countries to developing countries under the Paris Agreement, which was ultimately missed but enhanced through the post-2025 goal for finance (see UNFCCC, 2021a) and discussions around long-term climate finance (see UNFCCC, 2021b)--are therefore likely to be key to help ensure that the most vulnerable countries can finance adaptation strategies and build resilience to a global threat to which they have contributed relatively little. Building resilience to the physical impacts of climate change requires significant public- and private-sector investments, with payback often delayed by several years or even decades. At the same time, countries require better data to help inform climate risk and vulnerability assessments, as well as better information about adaptive capacity and monitoring the efficacy of adaptation measures. One first step is understanding that countries will be exposed to different types of physical risk--as highlighted in our exposure metrics.

The scenario analysis presented here reinforces our expectations that physical climate risks are likely to become more material in our sovereign rating analysis over time, as chronic and acute risks become more frequent and severe, better data becomes available, and uncertainty declines about the materialization and visibility of impacts. 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, helping place more emphasis on the ability and willingness of governments to actively seek to mitigate the negative impacts of climate risks and to pursue effective adaptation strategies.

Related Research And Criteria

S&P Global Ratings research

- Economic Research: Green Spending Or Carbon Taxes (Or Both): How To Reach Climate Targets, And Grow Too, By 2030?, Nov. 3, 2021
- Model Behavior: How Enhanced Climate Risk Analytics Can Better Serve Financial Market Participants, June 24, 2021
- Damage Limitation: Using Enhanced Physical Climate Risk Analytics In The U.S. CMBS Sector, Feb. 19, 2021
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- Better Data Can Highlight Climate Exposure: Focus On U.S. Public Finance, Aug. 24, 2020
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- Space, The Next Frontier: Spatial Finance And Environmental Sustainability, Jan. 22, 2020
- Sink Or Swim: The Importance Of Adaptation Projects Rises With Climate Risks, Dec. 3, 2019
- The Role Of Environmental, Social, And Governance Credit Factors In Our Ratings Analysis, Sept. 12, 2019
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Appendix

Full results are presented in table A1, with limitations to our approach described thereafter.

Table A1

Complete Results For All 135 Rated Entities in Our Rated Universe: RCP4.5 In 2050

Rated Entities	Region	Readiness assessment	Total GDP exposure (wildfire, flood, sea level rise or storms)	GDP exposure based on agricultural land at risk of water stress	Agricultural land exposed to water stress	Population exposure (heat waves)
Kazakhstan	Central Asia	4	15%	2%	62%	0%
Tajikistan	Central Asia	6	100%	8%	39%	2%
Uzbekistan	Central Asia	5	82%	18%	77%	0%
Australia	East Asia & Pacific	1	65%	1%	42%	5%
China	East Asia & Pacific	3	25%	3%	49%	33%
Cook Islands	East Asia & Pacific	4	0%	0%	0%	100%
Fiji	East Asia & Pacific	5	100%	0%	0%	100%
Hong Kong	East Asia & Pacific	2	100%	0%	0%	100%
Indonesia	East Asia & Pacific	4	2%	1%	9%	100%
Japan	East Asia & Pacific	1	96%	0%	14%	49%
Malaysia	East Asia & Pacific	4	2%	0%	4%	100%
Mongolia	East Asia & Pacific	4	0%	2%	22%	0%
New Zealand	East Asia & Pacific	1	0%	0%	0%	41%
Papua New Guinea	East Asia & Pacific	6	100%	0%	0%	100%
Philippines	East Asia & Pacific	4	95%	3%	35%	100%
Republic of Korea (South Korea)	East Asia & Pacific	2	70%	0%	28%	40%
Singapore	East Asia & Pacific	1	17%	0%	0%	100%
Taiwan	East Asia & Pacific	2	100%	1%	11%	100%
Thailand	East Asia & Pacific	4	9%	0%	0%	58%
Vietnam	East Asia & Pacific	4	39%	0%	4%	60%
Albania	Europe	5	0%	8%	42%	100%
Andorra	Europe	2	0%	9%	96%	0%
Armenia	Europe	5	0%	11%	96%	7%
Austria	Europe	1	3%	0%	0%	0%
Azerbaijan	Europe	5	0%	6%	99%	3%
Belarus	Europe	5	0%	0%	0%	0%
Belgium	Europe	2	0%	1%	94%	0%
Bosnia and Herzegovina	Europe	5	0%	0%	0%	38%
Bulgaria	Europe	4	1%	2%	51%	78%
Croatia	Europe	4	0%	0%	0%	14%
Cyprus	Europe	3	1%	0%	0%	100%
Czech Republic	Europe	3	0%	0%	0%	0%
Denmark	Europe	1	0%	0%	0%	0%
Estonia	Europe	3	0%	0%	13%	0%
Finland	Europe	1	0%	0%	0%	0%

France	Europe	1	1%	0%	24%	14%
Georgia	Europe	5	0%	4%	54%	34%
Germany	Europe	1	1%	0%	12%	0%
Greece	Europe	3	0%	3%	66%	100%
Guernsey	Europe	2	0%	0%	0%	0%
Hungary	Europe	3	0%	0%	16%	0%
Iceland	Europe	2	0%	0%	0%	0%
Ireland	Europe	1	0%	0%	1%	0%
Italy	Europe	3	0%	1%	57%	64%
Jersey	Europe	2	0%	0%	0%	0%
Latvia	Europe	3	0%	0%	1%	0%
Liechtenstein	Europe	1	0%	0%	0%	0%
Lithuania	Europe	3	0%	0%	2%	0%
Luxembourg	Europe	1	0%	0%	4%	0%
Macedonia	Europe	4	0%	7%	90%	100%
Montenegro	Europe	4	0%	0%	0%	100%
Netherlands	Europe	1	19%	1%	27%	0%
Norway	Europe	1	0%	0%	0%	0%
Poland	Europe	4	0%	0%	0%	0%
Portugal	Europe	3	1%	2%	96%	3%
Romania	Europe	4	0%	1%	27%	37%
Russia	Europe	5	1%	0%	17%	5%
Serbia	Europe	4	1%	0%	2%	38%
Slovakia	Europe	3	0%	0%	0%	0%
Slovenia	Europe	3	0%	0%	0%	0%
Spain	Europe	2	0%	3%	92%	43%
Sweden	Europe	1	0%	0%	1%	1%
Switzerland	Europe	1	0%	0%	0%	0%
Turkey	Europe	4	2%	5%	83%	96%
Ukraine	Europe	5	1%	6%	60%	8%
U.K.	Europe	1	1%	0%	23%	0%
Argentina	Latin America & Caribbean	5	17%	1%	11%	6%
Aruba	Latin America & Caribbean	5	100%	0%	0%	100%
Bahamas	Latin America & Caribbean	4	100%	0%	0%	100%
Barbados	Latin America & Caribbean	5	100%	0%	0%	100%
Belize	Latin America & Caribbean	6	100%	0%	0%	100%
Bolivia	Latin America & Caribbean	5	14%	0%	2%	100%
Brazil	Latin America & Caribbean	5	9%	0%	0%	64%
Chile	Latin America & Caribbean	4	60%	2%	50%	9%
Colombia	Latin America & Caribbean	4	3%	0%	0%	100%
Costa Rica	Latin America & Caribbean	4	15%	0%	0%	100%
Curacao	Latin America & Caribbean	5	100%	0%	0%	100%
Dominican Republic	Latin America & Caribbean	4	100%	4%	84%	100%

Ecuador	Latin America & Caribbean	5	0%	1%	10%	100%
El Salvador	Latin America & Caribbean	5	57%	0%	0%	100%
Falkland Islands	Latin America & Caribbean	2	0%	0%	0%	0%
Guatemala	Latin America & Caribbean	6	69%	0%	0%	100%
Honduras	Latin America & Caribbean	5	96%	0%	0%	100%
Jamaica	Latin America & Caribbean	6	100%	0%	0%	100%
Mexico	Latin America & Caribbean	5	35%	2%	61%	94%
Montserrat	Latin America & Caribbean	5	0%	0%	0%	100%
Nicaragua	Latin America & Caribbean	6	98%	0%	0%	100%
Panama	Latin America & Caribbean	3	2%	0%	0%	100%
Paraguay	Latin America & Caribbean	5	1%	0%	0%	6%
Peru	Latin America & Caribbean	4	11%	1%	17%	100%
Suriname	Latin America & Caribbean	6	100%	0%	0%	100%
Trinidad and Tobago	Latin America & Caribbean	5	100%	0%	0%	100%
Turks and Caicos Islands	Latin America & Caribbean	4	100%	0%	0%	100%
Uruguay	Latin America & Caribbean	3	1%	0%	0%	0%
Bahrain	MENA	4	100%	0%	0%	100%
Egypt	MENA	5	2%	3%	33%	93%
Iraq	MENA	6	29%	1%	90%	100%
Israel	MENA	2	0%	1%	99%	100%
Jordan	MENA	6	0%	5%	100%	100%
Kuwait	MENA	3	0%	0%	100%	100%
Lebanon	MENA	6	0%	3%	97%	100%
Malta	MENA	3	0%	0%	0%	100%
Morocco	MENA	5	1%	11%	95%	15%
Oman	MENA	5	5%	2%	88%	92%
Qatar	MENA	2	0%	0%	0%	100%
Saudi Arabia	MENA	4	0%	2%	99%	100%
Saint Helena	N/A	5	0%	0%	0%	95%
Bermuda	North America	2	0%	0%	0%	100%
Canada	North America	1	27%	0%	37%	2%
U.S.	North America	1	44%	0%	51%	30%
Bangladesh	South Asia	4	90%	0%	0%	21%
India	South Asia	4	52%	10%	62%	40%
Pakistan	South Asia	5	20%	17%	81%	48%
Sri Lanka	South Asia	5	5%	5%	73%	100%
Angola	Sub-Saharan Africa	6	1%	0%	0%	100%
Benin	Sub-Saharan Africa	5	31%	0%	0%	100%
Botswana	Sub-Saharan Africa	5	19%	0%	0%	69%
Burkina Faso	Sub-Saharan Africa	6	99%	0%	0%	100%
Cape Verde	Sub-Saharan Africa	5	100%	0%	0%	100%
Cameroon	Sub-Saharan Africa	5	40%	0%	0%	100%
Congo-Brazzaville	Sub-Saharan Africa	6	11%	0%	0%	100%

Cote d'Ivoire	Sub-Saharan Africa	4	2%	0%	0%	100%
Democratic Republic of the Congo	Sub-Saharan Africa	6	18%	0%	0%	100%
Ethiopia	Sub-Saharan Africa	6	93%	1%	2%	100%
Ghana	Sub-Saharan Africa	5	16%	0%	0%	100%
Kenya	Sub-Saharan Africa	5	2%	0%	0%	100%
Mozambique	Sub-Saharan Africa	6	14%	0%	0%	63%
Nigeria	Sub-Saharan Africa	6	3%	0%	0%	100%
Rwanda	Sub-Saharan Africa	5	0%	0%	0%	100%
Senegal	Sub-Saharan Africa	4	26%	0%	0%	100%
South Africa	Sub-Saharan Africa	5	0%	1%	27%	45%
Togo	Sub-Saharan Africa	6	32%	0%	0%	100%
Uganda	Sub-Saharan Africa	6	0%	0%	0%	100%
Zambia	Sub-Saharan Africa	6	10%	0%	0%	72%

Note: Brown to green coloring indicates higher to lower exposure. MENA--Middle East & North America. N/A—Not applicable. Source: S&P Global Ratings.

Limitations

Our estimates are constrained by data availability and subject to uncertainty, as economic structures and responses to hazards are likely to change over time. For example, Formetta and Feyen (2019) show that the loss rates of climate hazards have declined globally over the past three decades for both low- and high-income countries. As our economic impact approach is static, it does not take into account second-order effects, such as impacts of those events on migration flows and trade patterns or relative price changes that may occur as a result.

We also acknowledge that the analysis omits some of the impacts of physical hazards. For example, to our knowledge there were no loss rate estimates for wildfires at the time of the study, so the actual impact of physical hazards may be under- or over-estimated. Moreover, climate hazards like heat waves can also impact crop yields or human health, which we don't account for in our study. Interdependencies between hazards (that is, one hazard causing another, such as a storm leading to flooding or a storm surge), and feedback loops (for example, wildfires cause acute impacts but may have positive benefits, such as preventing succession to scrubland or encouraging seed germination), are also not captured, but is a limitation in climate risk modeling studies more generally. Nonetheless, we note that our GDP exposure estimates are very close to the NGFS' current policies scenario, which points to losses of around 5% of GDP by 2050 on a global scale. While forecasting ability naturally declines over time, we note that climate change under current policies is expected to increase further beyond 2050, with average temperatures rising by 2.7°C on average by 2100 resulting in losses potentially piling up well above our 2050 estimates.

With this context, the readiness factor is not accounted for in our "economic impact layer" (see chart 1), as both studies used in that step provide estimates that are not extracted through country-specific regressions. Roson and Sartori (2016) compute their labor productivity impact estimates using wet bulb globe temperature estimates, which are purely linked to existing temperature and humidity in each country studied and then tied to work intensity of each sector--this can be viewed as independent of a sovereign's current economic or political situation. Formetta and Feyen (2019) report the historical median loss rates for the physical events under study by splitting them into two income buckets. Although some minor overlap may occur here, the two categories remain very broad and still feature countries with very different institutions and economic strength. The more likely impact is that physical risk losses (expressed in GDP terms) are overestimated for higher-income countries and underestimated for lower-income countries.

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