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Contents

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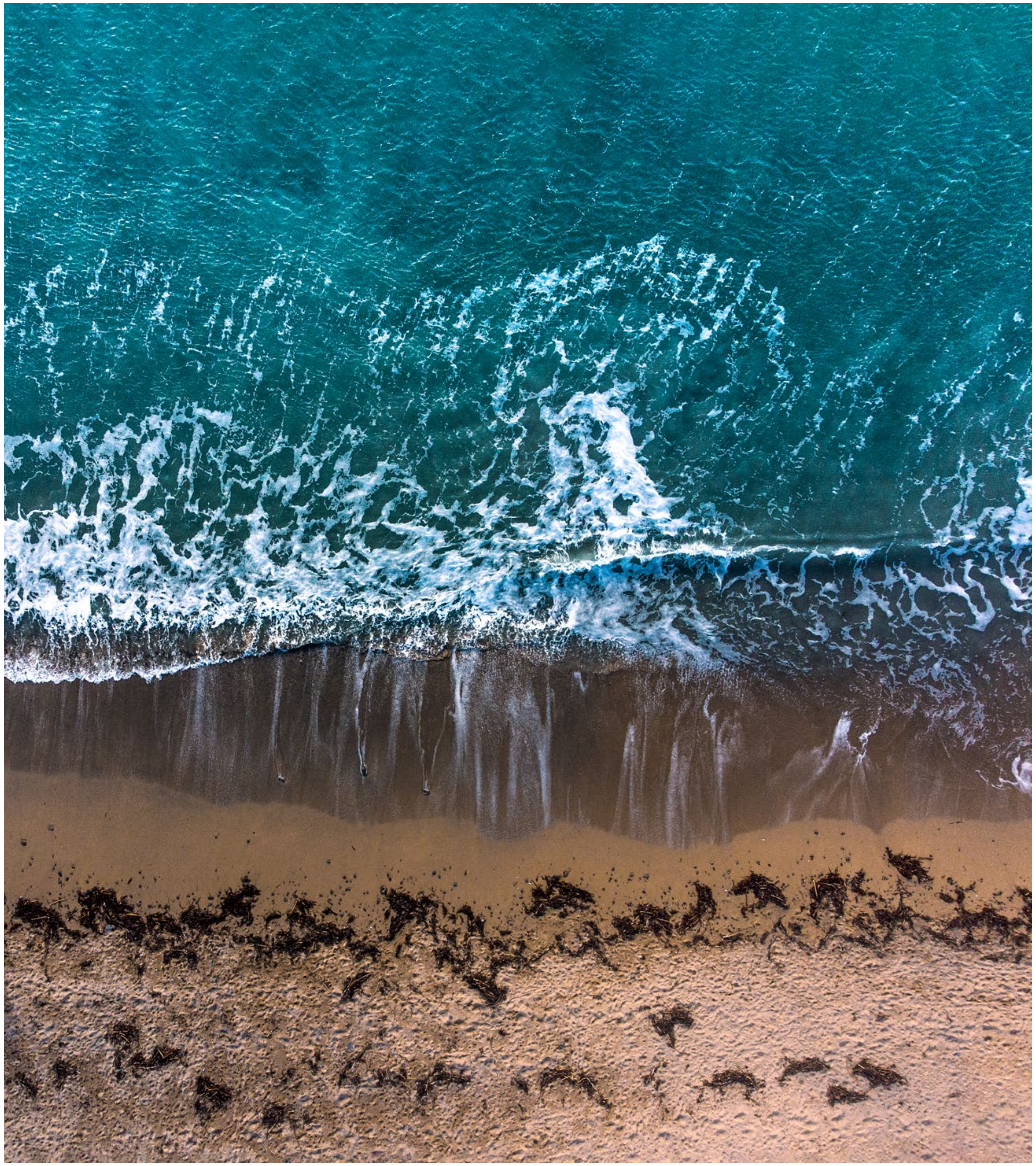
Sustainable1



Douglas L. Peterson
President and CEO
S&P Global

Foreword

Welcome to the first edition of the S&P Global Sustainability Quarterly. Our world-class team of writers, editors, designers, analysts, and researchers has brought together our best insights to help you understand the latest trends and measure progress toward a low-carbon, sustainable future. They've done this by reformulating our popular Sustainability Yearbook. The trends shaping business and finance are moving rapidly and so too must our coverage of these changes. Now, instead of waiting for an annual publication highlighting key developments, we'll deliver our latest data, analytics, and research each quarter.

In this issue, we turn our attention to the topic of climate change as Climate Week begins in New York. Climate Week NYC is all about moving from ambitions to actions. In these pages you'll find powerful, perceptive commentary about important climate-related issues impacting companies, countries and investors. The stories are a guide to help you make sense of the uncertainty, risks and opportunities presented by our warming planet.

We all must take steps to accelerate the pace of change to limit carbon emissions. Our base case scenario indicates that only 19% of global greenhouse gas emissions will be reduced between 2021 and 2050. All of us at S&P Global are committed to providing the transparency and analytics to help you make decisions that will advance the green energy transition. ■

Introduction

Around the globe, countries are facing growing exposure to the physical impacts of climate change. These impacts take center stage as we head into a busy fall season of climate events — starting with Climate Week NYC in September and culminating with the U.N.'s Climate Change Conference, known as COP27, in November. The inaugural **S&P Global Sustainability Quarterly** is a roadmap to understanding this evolving climate landscape.

Climate Risk & Resilience

Research from S&P Global Ratings explores the vulnerability and readiness of more than 130 countries to climate change over the next 30 years — and the GDP at stake under different climate scenarios. The economic impact is significant: an estimated 4% of global GDP could be exposed to losses under our current trajectory on commitments to address climate change, ranging up to an estimated 18% of GDP at risk for certain countries. For context, the impact of the COVID-19 pandemic on global GDP in 2020 was negative 3.3%, according to the World Bank.

Economic loss estimates show that climate hazards result in GDP losses that are on average 3.6 times greater for lower-income countries than wealthier ones. Economic losses are likely to be higher and more persistent for those same countries, which have less capacity to adapt, weaker institutions and fewer financial resources.

At the same time, we find that international cooperation and support can help the most vulnerable countries finance a rising adaptation gap while building resilience to climate change, a problem to which they have contributed relatively little. Such collaboration will be key heading into global conversations between the public and private sectors at the upcoming COP27.

Sustainable Finance

Research from S&P Global Sustainable1, in collaboration with S&P Global Market Intelligence and S&P Dow Jones Indices, provides a snapshot of the current state of equity investing. Our data suggests that there is a long way to go toward aligning investor capital with the pathway that averts the worst consequences of climate change. From a universe of nearly 12,000 equity mutual funds and exchange-traded funds representing more than $20 trillion in market value, we found that about 11% are currently aligned with the Paris Agreement goal of limiting global warming to "well below" 2°C.

Carbon Pricing

In this environment, government policies seeking to transition economies to net-zero emissions are also poised to increase globally. Research from S&P Global Ratings, S&P Global Commodity Insights, and S&P Global Sustainable1 delves into one such approach — carbon pricing, which many economists view as one of the most efficient policy levers to encourage reductions of GHG emissions. At present, carbon pricing regulations are in place for around a quarter of global emissions. Over time, we expect more countries will have to adopt some form of carbon pricing as part of a mix of policy approaches to achieving the Paris Agreement's goal.

Assuming such a future, with more widespread carbon pricing policies, it seems clear that companies with a greater ability to adjust their business models and operations will be less exposed — and perhaps better able to compete. Over time, investor demand for climate-related disclosures from companies is also likely to increase.

Energy Transition

The heightened urgency of the climate crisis has accelerated calls for the global energy industry to shift from fossil-based systems of energy production and consumption — including oil, natural gas, and coal — to renewable energy sources. But, as research from S&P Global Commodity Insights shows, accelerating the expansion of renewables generation, in line with limiting global warming to less than 2°C per year, would require significant additional momentum beyond current market economics.

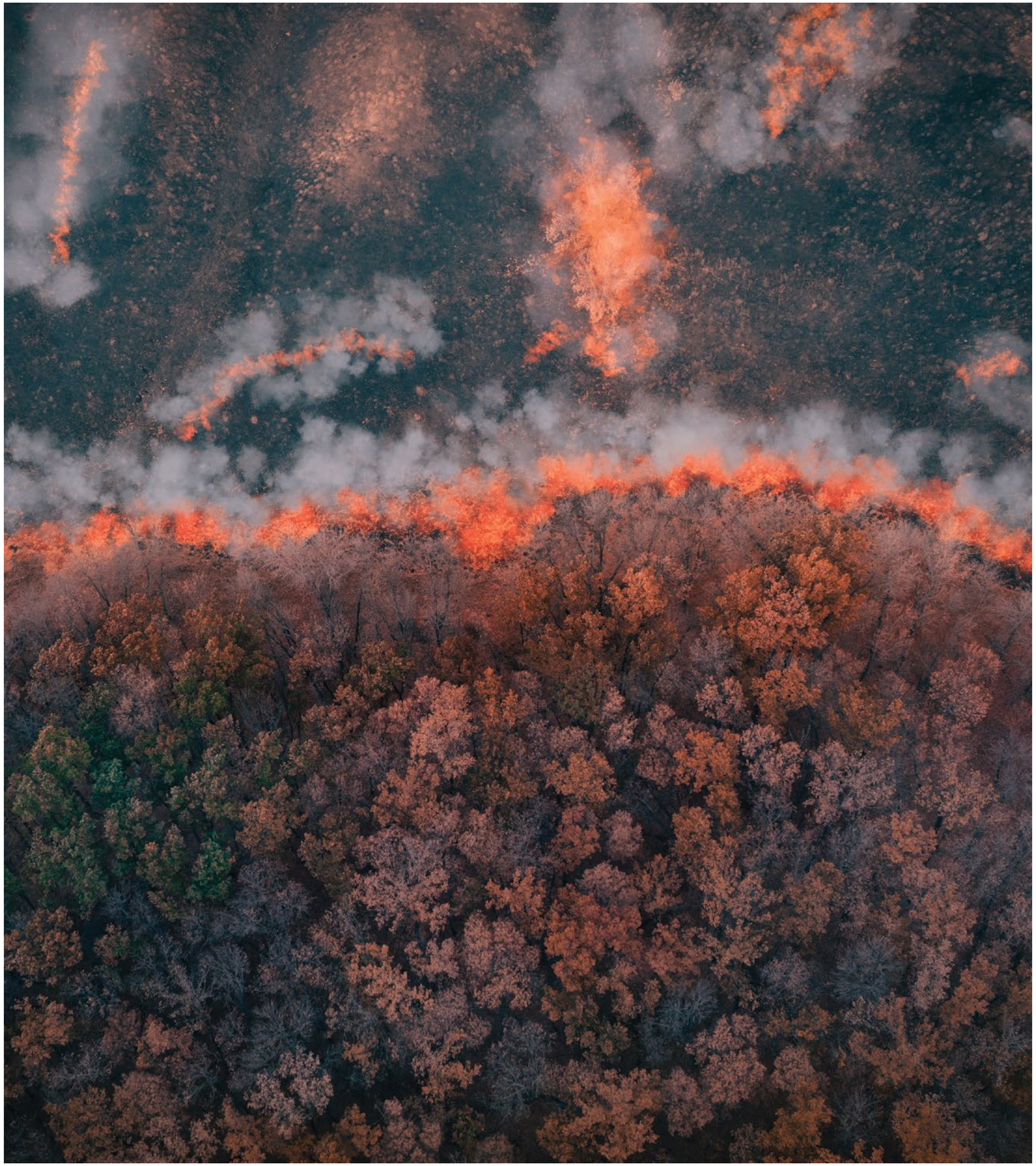
Future of Copper

The path to the energy transition is not always straightforward. Take copper, for example — this "metal of electrification" is essential to all energy transition plans. Deeper electrification requires wires, and wires are primarily made from copper. Technologies critical to the energy transition, such as electric vehicles, charging infrastructure, solar photovoltaics, wind and batteries, all require much more copper than conventional fossil-based counterparts.

Research from S&P Global's Economics & Country Risk, Commodity Insights, and Mobility teams shows that this growing appetite for copper could be an obstacle for energy transition and climate goals. Demand for copper will double by 2035, opening a supply gap that threatens climate goals and poses serious challenges to reaching net zero emissions by 2050. There is no way to forestall the projected shortages in copper without taking steps to increase supply. Our research identifies three priority areas for consideration.

Understanding the landscape for climate change can help identify solutions. As the sustainability world works at speed to turn climate goals into action, we hope our quarterly sustainability research journal will serve as a useful tool in facilitating such understanding and driving measurable progress. ■

Richard Mattison
President, S&P Global Sustainable1



Weather warning:
Assessing countries' vulnerability to economic losses from physical climate risks

Research from S&P Global Ratings explores the vulnerability and readiness of more than 130 countries to climate change over the next 30 years — and the GDP at stake under different climate scenarios. Economic loss estimates show that climate hazards result in GDP losses that are on average 3.6 times greater for lower-income countries than wealthier ones. Economic losses are likely to be higher and more persistent for those same countries, which have less capacity to adapt, weaker institutions, and fewer financial resources.

Published on April 27, 2022.

This report does not constitute a rating action.

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.

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.

▶ **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 by 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 and 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 risks to security and countries' governance structures."

That said, for some countries, the physical impacts of climate change may begin to play out only over time — especially for 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 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 have discussed (see "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.

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.

Another component affecting countries' vulnerability is their readiness and ability to adapt as quickly as required. Understanding of 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.

Scenario analysis may help countries plan for an uncertain future

Despite advances in climate science in recent years, particularly the understanding of 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.

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 widely 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;

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.

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.

- 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.

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

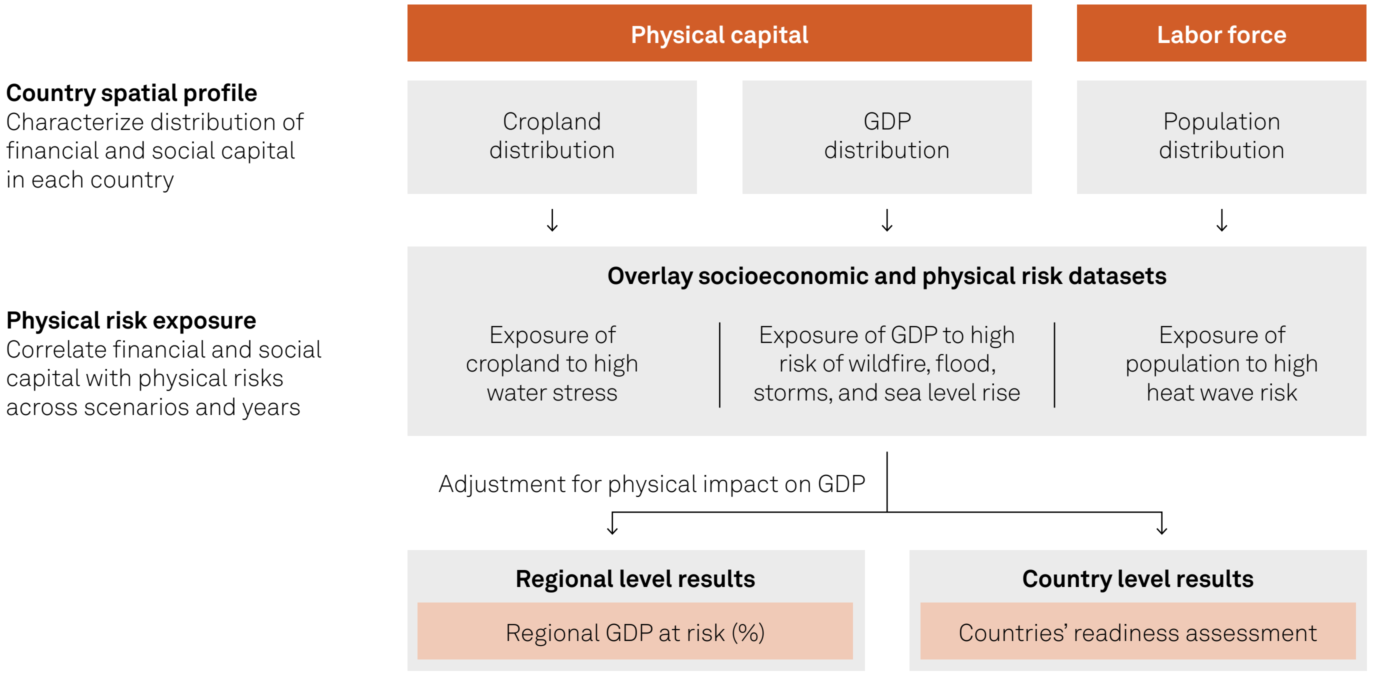
We assess the vulnerability of 135 countries within our rated universe to different climate hazards — heat waves, flooding, sea level rise, water stress and wildfire — over the next 30 years, assessing countries' readiness to adapt (see chart 1). We also include storms, based on historical exposure due 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.

CLIMATE RISK & RESILIENCE

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 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).

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 and 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.

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 for 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 use 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.

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.

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.

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 Ratings' 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 the 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.

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 for 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.

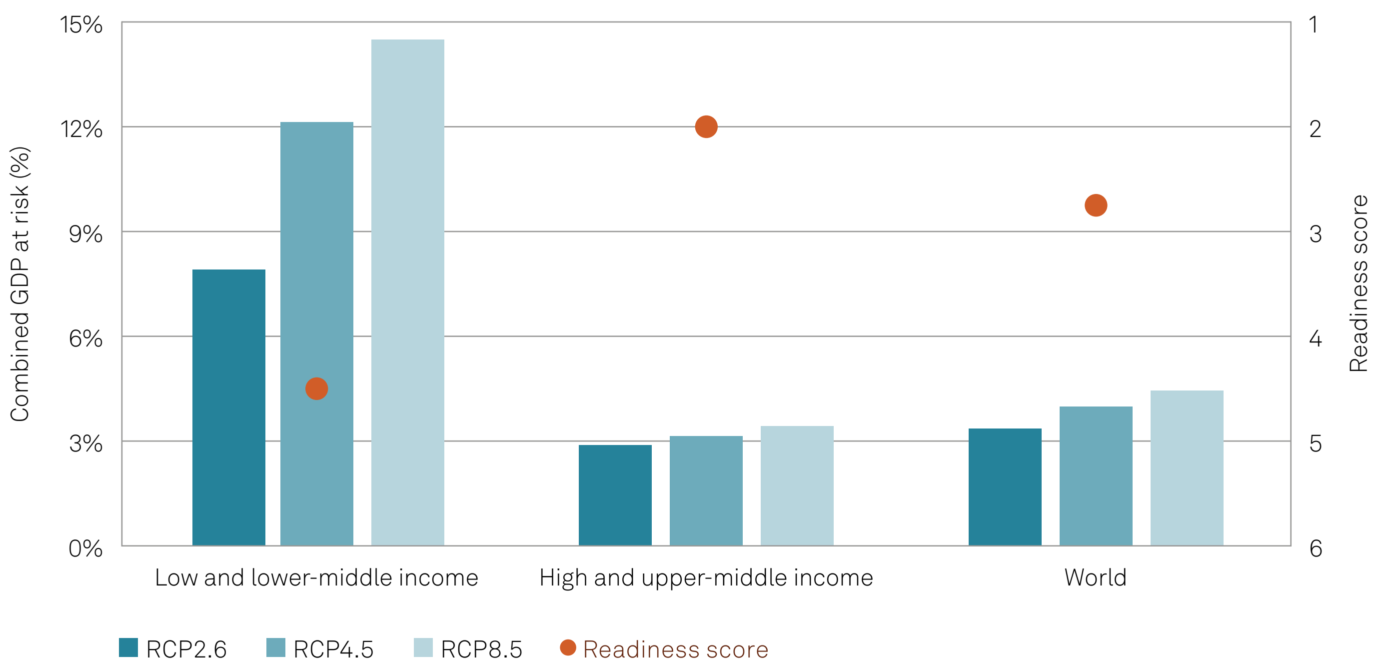
These risks and their associated costs are expected to increase over time as they are projected to become more frequent and severe, particularly from mid-century to 2100. That said, countries may be able to mitigate some of these losses depending on their readiness and capacity to adapt. (The following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

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

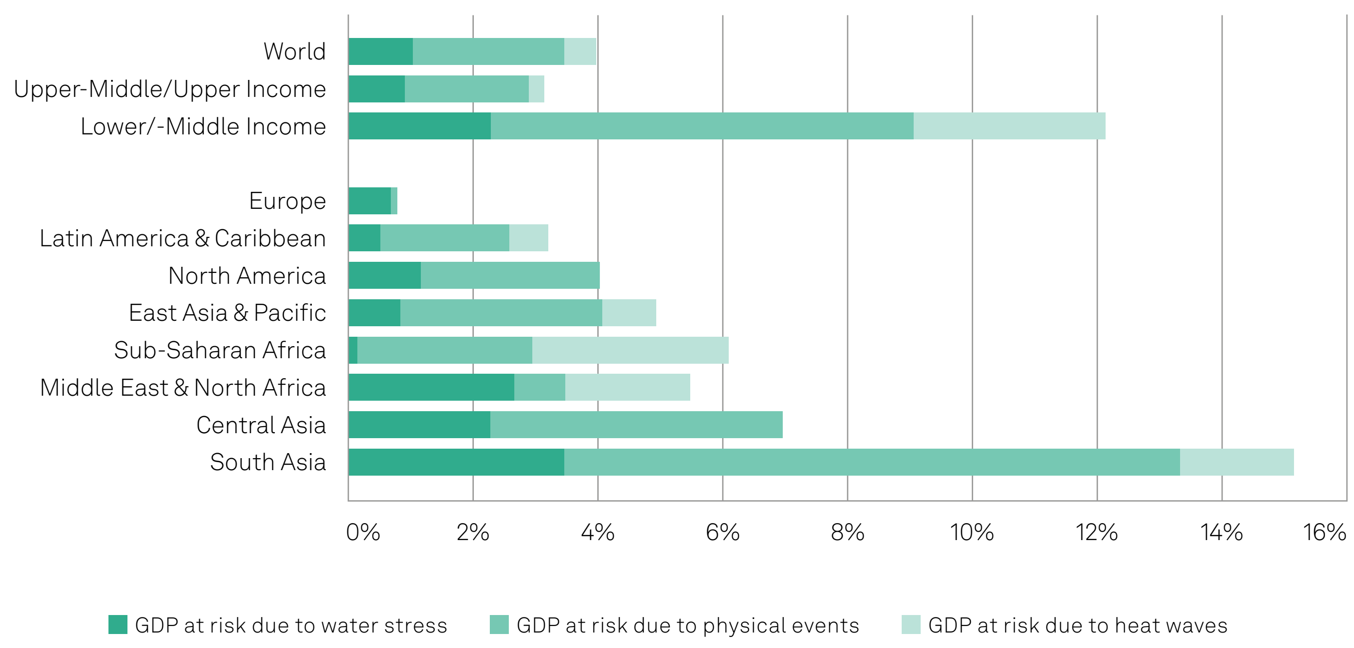
Chart 2: **Lower-income countries are more at risk of physical climate hazards in 2050**
Combined GDP at risk (%) and readiness score



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

Chart 3: **South Asia is more than 10 times more exposed than Europe**

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



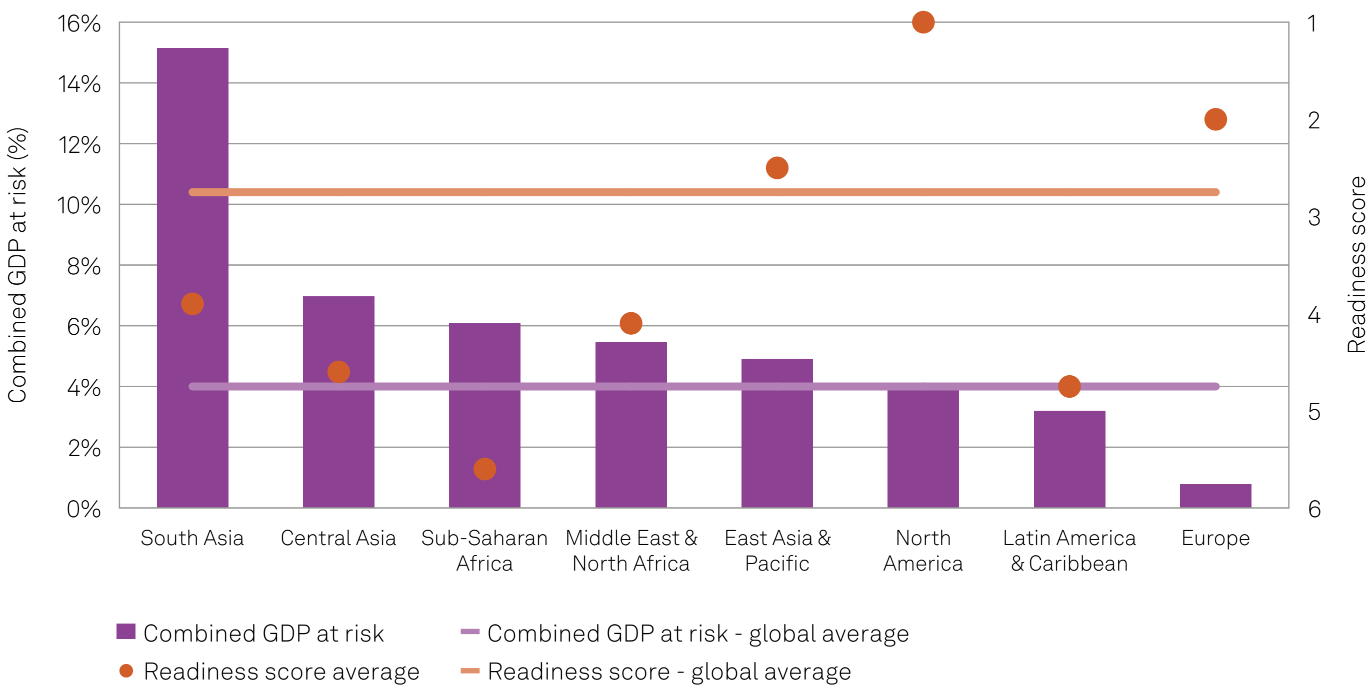
Note: Countries' income and regional classification is based on World Bank.
Sources: S&P Global Ratings, S&P Global Sustainable1 (2022).

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.

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, it is our 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

CLIMATE RISK & RESILIENCE

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.

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.

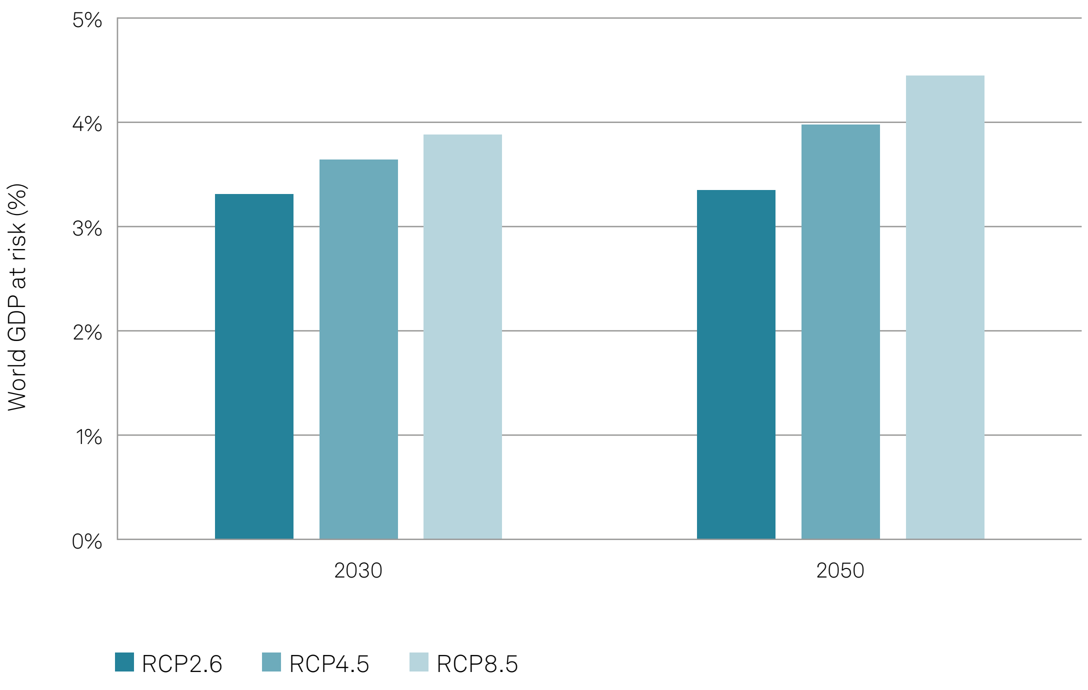
Our 2020 GDP at risk estimates highlight that a large part of the world is already exposed to climate hazards, in particular South Asian countries. However, the losses incurred so far have been much lower than our GDP at risk estimates. For example, in the U.S. and EU, losses have amounted to 0.6% and 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.

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

Chart 5: **Less warming is better for future incomes globally**

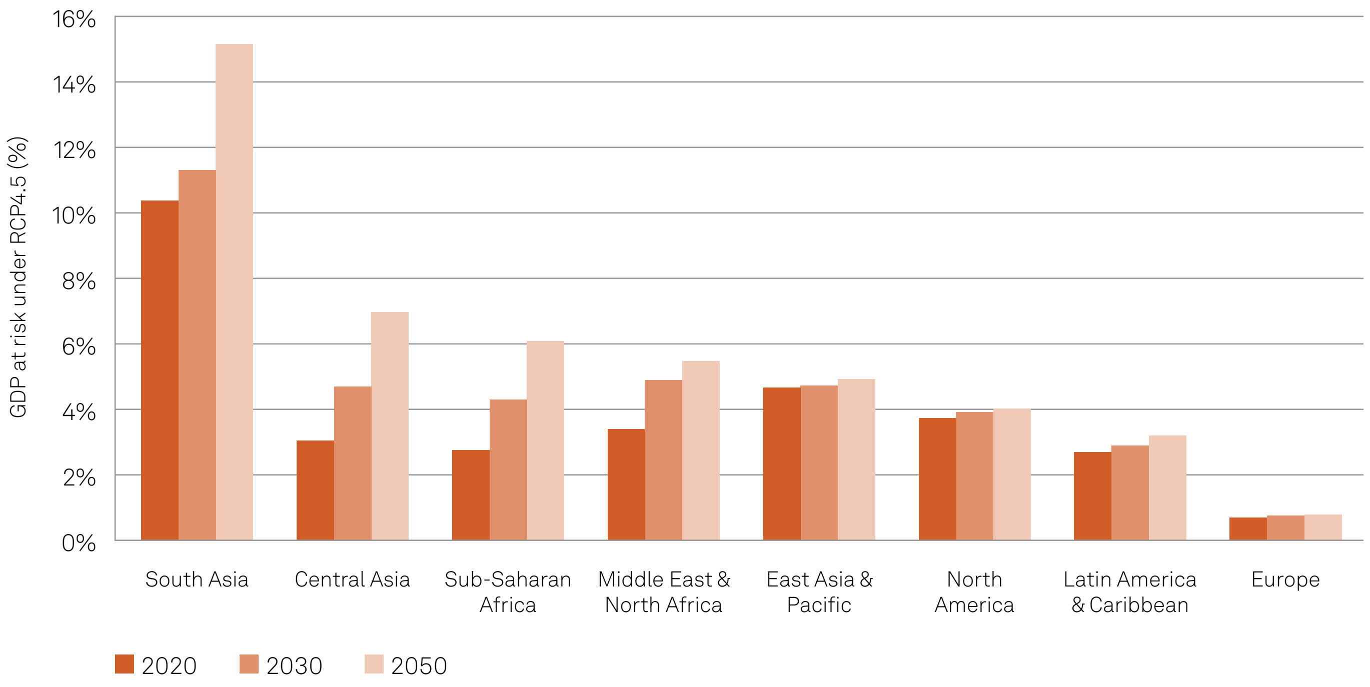
Percentage of world GDP at risk under different climate change scenarios



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

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).

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.

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).

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 more 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.

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 rated entities included in our analysis, as well as limitations to our approach.

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. Mainland 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.

Under a moderate stress (RCP4.5) scenario and readiness, 2050

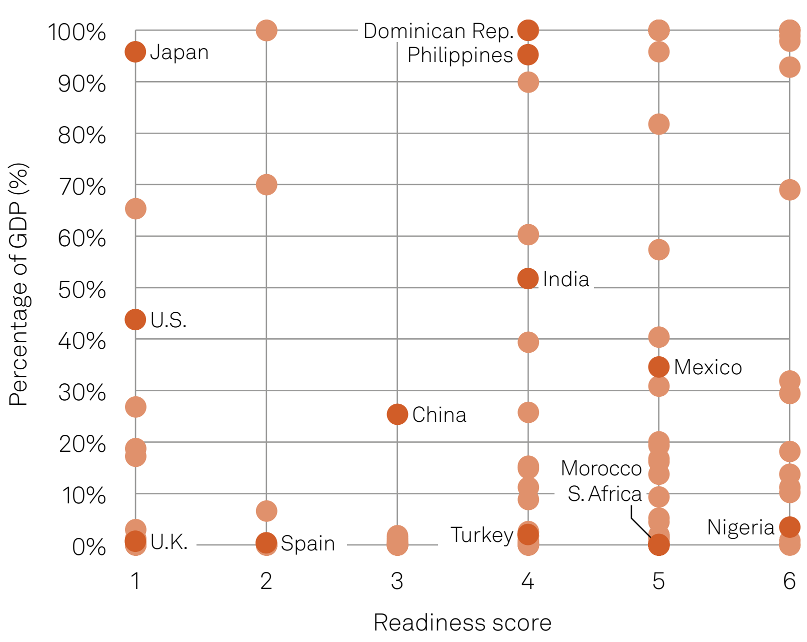
Charts 7-9 provide a clearer picture of where countries stand in the face of climate change. We expect that countries in the upper-right quadrant of the charts could face the greatest impacts from climate change, while those in the lower-left quadrant are likely to face more modest losses. For economies 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.

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.

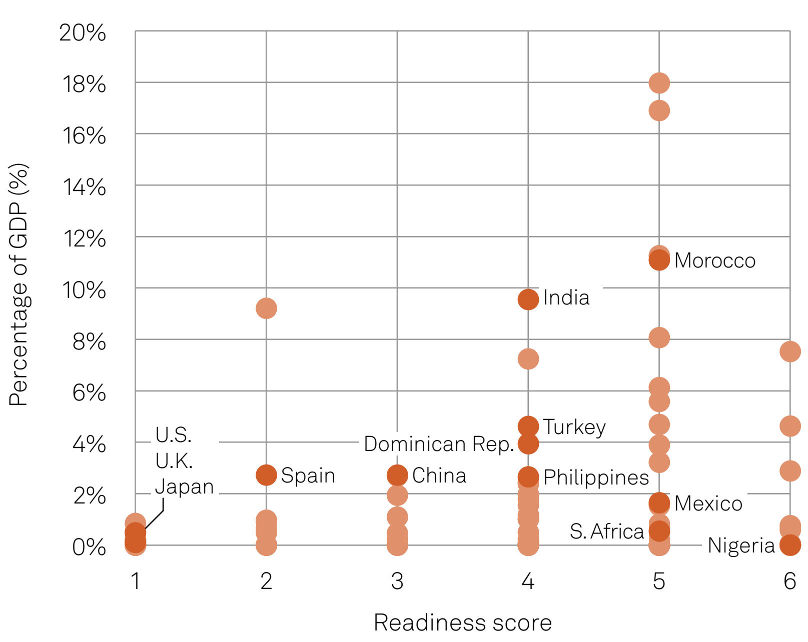
Readiness of South Asian countries is also in the medium to lower part of the range. India and Bangladesh are assessed to be better prepared to face those risks owing to stronger economies and institutions.

Chart 7: **GDP exposure to wildfire, flood, sea level rise, or storms***



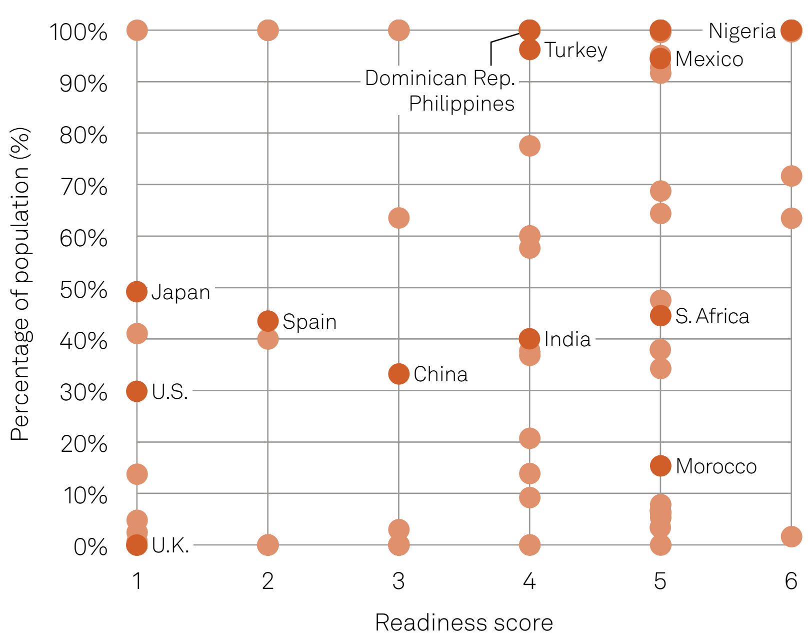
Note: A lower readiness score means better readiness. *Storms exposure taken as baseline only.
Sources: S&P Global Ratings, S&P Global Sustainable1 (2022)

Chart 8: **GDP exposure to agricultural land at risk of water stress**



Note: A lower readiness score means better readiness.
Sources: S&P Global Ratings, S&P Global Sustainable1 (2022)

Chart 9: **Population exposure to heat waves**



Note: A lower readiness score means better readiness.
Sources: S&P Global Ratings, S&P Global Sustainable1 (2022)

Table 3: **Rated entities 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

Rated entity	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).

Typhoons and sea level rise will become particularly acute in East Asia and for Pacific Islands

Our scenario analysis highlights 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 mainland 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.

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.

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 entity	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)
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%
Mainland 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).

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.

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. The islands are likely to be much more affected by physical risks — like storms and sea level rise — similar 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.

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.

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.

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

Table 5: **Rated entities in Latin America and Caribbean in 2050 under 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 entity	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%

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).

CLIMATE RISK & RESILIENCE

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 entity	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%

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).

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 vary 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).

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.

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.

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

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).

Table 8: **Rated entities 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

Rated entity	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).

CLIMATE RISK & RESILIENCE

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 entity	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%
North 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).

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.

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. Similar 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.

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 ensuring 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.

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

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. ■

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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 entity	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).

CLIMATE RISK & RESILIENCE

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
- ESG Overview: Global Sovereigns, Feb. 3, 2021
- Scenario Analysis Shines A Light On Climate Exposure: Focus On Major Airports, Nov. 5, 2020
- Better Data Can Highlight Climate Exposure: Focus On U.S. Public Finance, Aug. 24, 2020
- The Energy Transition: The Clock Is Ticking For Middle East Hydrocarbon Exporters, Feb. 16, 2020
- 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
- Plugging The Adaptation Gap With High Resilience Benefit Investments, Dec. 7, 2018
- Economic Research: Why It May Make Economic Sense To Tackle Global Warming, Dec. 5, 2018
- Criteria | Governments | Sovereigns: Sovereign Rating Methodology, Dec. 18, 2017
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Other research

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CLIMATE RISK & RESILIENCE

Appendix

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

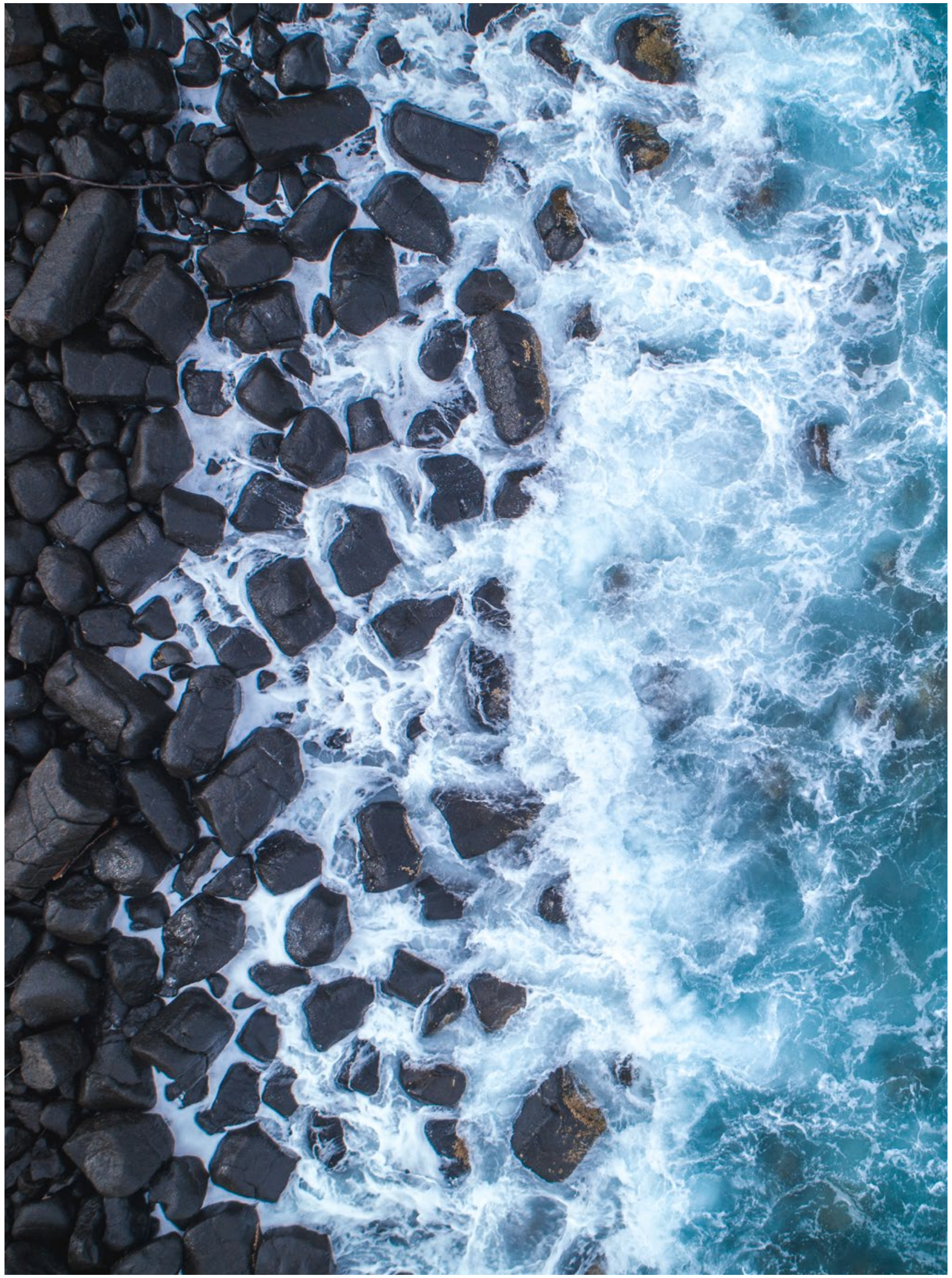
Table A1: **Complete results for all 135 entities in our rated universe: RCP4.5 In 2050**

Rated entity	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%
Mainland 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%
North 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: Orange to blue coloring indicates higher to lower exposure. MENA—Middle East & North America. N/A—Not applicable.
Source: S&P Global Ratings.



CLIMATE RISK & RESILIENCE

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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Green funds have a Paris alignment problem

Research from S&P Global Sustainable1 in collaboration with S&P Global Market Intelligence and S&P Dow Jones Indices provides a snapshot of the current state of equity investing. From a universe of nearly 12,000 equity mutual funds and exchange-traded funds representing more than $20 trillion in market value, we found that about 11% are currently aligned with the Paris Agreement goal of limiting global warming to "well below" 2°C. In other words, there is a long way to go toward aligning investor capital with the pathway that averts the worst consequences of climate change.

Published on June 7, 2022

Key takeaways

- From a universe of nearly 12,000 equity mutual funds and exchange-traded funds representing more than $20 trillion in market value, S&P Global Sustainable1 found that about 11% are currently aligned with the Paris Agreement goal of limiting global warming to “well below” 2°C.
- The analysis also identified more than 300 funds that use green or environmental language in their names or to describe their approach, as well as a subset of 51 climate-focused funds. Only about 12% of green funds are on budget to meet the goal of the Paris Agreement — nearly the same proportion as the broader universe of funds. An even smaller proportion of climate-focused funds are aligned.
- While many green and climate funds are over budget on emissions, green funds as a group are slightly closer to Paris alignment than the broad fund universe, and by a statistically significant amount.
- One in three green funds and climate funds are on a trajectory to overshoot even a less ambitious 3°C warming scenario, in which flooding, drought and sea level rise would pose severe risks to human life and society.
- The findings provide a snapshot of the current state of equity investing — showing there is a long way to go toward aligning investor capital with the pathway that averts the worst consequences of climate change.

▶ **Equity mutual funds and exchange-traded** funds around the world use green language to signal that their portfolios support the energy transition, address environmental concerns or combat climate change. But wide misalignment with the Paris Agreement goal of limiting global warming is the current reality for most of these funds, according to a new analysis by S&P Global Sustainable1 — and this could undermine the eco-friendly or climate-conscious signals they send to investors.

Under the Paris Agreement, more than 190 parties committed to limiting the global rise in greenhouse gas emissions to “well below” 2°C, and preferably 1.5°C, relative to preindustrial levels. The agreement brings together nations from around the world to work toward a common climate goal. Limiting warming to this target means reaching net zero emissions by midcentury.

Our analysis shows that based on current trajectories, equity funds across the board have a long way to go to meet the goal of the Paris Agreement. We started with a global universe of nearly 12,000 equity mutual funds and exchange-traded funds representing more than $20 trillion in market value. We then overlaid S&P Global Trucost Paris Alignment data covering more than 17,000 companies on the fund holdings to assess the funds’ warming trajectory. This data sums actual Scope 1 and Scope 2 emissions from 2012 to the most recent available historical data, and then forecasts emissions through 2025, comparing trends in those emissions with the rates of decarbonization that would enable achievement of different temperature scenarios.

The analysis then takes an additional step of calculating the budget alignment per $1

Green funds have a Paris alignment problem

		3°C	2°C	1.5°C
Broad fund universe	S&P Global Sustainable1 analyzed nearly **12,000 ETFs** and mutual funds with market value of **more than $20 trillion**.	In that broad fund universe, we found that **more than half** of the funds are aligned with a **3°C** warming scenario.	About **1 in 3 funds** are aligned with a **2°C** warming scenario.	And about **11% of funds** are aligned with the warming scenario **"well below" 2°C** called for in the Paris Agreement.
Green funds	Within that broad fund universe, S&P Global Sustainable1 identified **more than 300 funds** with market value of more than **$350 billion** that have green language in the fund name or fund description.	**2 out of 3** of these green funds are on track to limit warming to **3°C**.	About **4 in 10** green funds align with a **2°C** warming scenario.	Only a **slightly higher percentage** of green funds, 12%, are aligned with the **"well below" 2°C** warming scenario, compared to the broad universe of funds.
Climate funds	Within the green fund universe, we also identified a subset of **51 climate-focused funds** with more than **$30 billion** in market value using a more targeted list of keywords related specifically to climate, net zero and carbon.	**2 out of 3** climate funds are on track to limit warming to **3°C**.	A similar proportion of climate funds, about **4 in 10**, currently align with **2°C**.	**5 of the 51 climate funds**, or slightly less than 10%, are aligned with the **"well below" 2°C** warming scenario.

Data as of April 19, 2022.
Analysis uses S&P Global Trucost Paris Alignment data to assess the difference between a company’s projected pathway for Scope 1 and Scope 2 greenhouse gas emissions and the required pathway to reach alignment with three different goals from 2012 to 2025. The most ambitious is a goal of limiting warming to “well below” 2°C, or 1.5°C. The second is a goal of limiting warming to 2°C. The third and least ambitious is a goal of limiting warming to 3°C.
Sources: S&P Global Trucost; S&P Global Sustainable1

million invested, which puts the budget in perspective relative to the size of the portfolio’s total market value as a measure of the investor’s responsibility. The analysis does not name specific funds as the findings point to misalignment across the green fund cohort and across the broader universe.

Within that broad fund universe, we identified more than 300 funds representing more than $350 billion in market value that use green or environmental language in their fund names or to describe their investment objectives. Within that green fund universe, we also identified a subset of 51 climate-focused funds using a more targeted list of keywords related specifically to climate, net zero and carbon. Many funds rely on sustainability language to attract environmentally conscious, climate-conscious or global warming-conscious investors. As climate change increases in urgency, understanding decarbonization pathways becomes increasingly important — even for funds that don't explicitly state Paris alignment as a goal.

We found that approximately 11% of the broad fund universe is on track to limit global warming to "well below" 2° above preindustrial levels by the year 2100. The data for our analysis treats the term "well below 2°" as equivalent to 1.5°, which is the target scientists say the world must hit to avoid the worst impacts of climate change.

For the green fund universe, results were only slightly better. Approximately 12% of green funds representing about $31 billion in market value were under their carbon budgets in a scenario of limiting global warming to "well below" 2°. In the smaller climate fund group, only one in 10 were aligned with 1.5° based on their current holdings.

The data suggests that the fund holdings are struggling to keep their emissions in check. This analysis does not purport to measure whether funds are mislabeled, are seeking to mislead investors or are engaging in greenwashing. Indeed, many of the over-budget green funds analyzed exclude fossil fuels, have a focus on renewables, or invest in companies driving the energy transition forward, such as electric vehicle manufacturers or climate technology solutions.[1] Few funds state Paris alignment as a goal, and funds may have a wide array of other green objectives that benefit the environment or help address climate change. Some funds also seek to invest in and engage with emissions-heavy companies, using their clout as shareholders to direct companies toward decarbonization. Carbon transition indices may also include heavy emitters but be designed to rebalance in favor of constituents that make progress on decarbonization over time. Even so, green funds as currently constructed are widely over budget according to the Trucost data forecasts through 2025, suggesting that many of their holdings are behind schedule in controlling their emissions and sourcing greener energy. A company or fund could satisfy its own definition of climate-conscious or green without being Paris aligned. But a fund that presents itself as climate-friendly because of fossil fuel exclusion or a focus on renewable energy but does not measure alignment with the 1.5° or 2° pathway (and could be misaligned even against a less ambitious 3°C warming scenario) is arguably missing the forest for the trees.

This issue is front and center as the trend of climate-focused investing has gone mainstream. Assets under management held in green funds are surging. Total AUM using a climate change or carbon criterion hit $4.18 trillion in 2020, up 39% from 2018, according to US SIF.[2] The menu of investment products seeking to address climate concerns has grown in tandem. In 2018, there were fewer than 50 equity funds with an environmental or climate-related purpose or strategy; by 2021, there were more than 400, according to Morningstar. Sustainability-minded investors are increasingly viewing a company's alignment with 1.5° or 2° as a proxy for a robust environmental strategy, and they are heeding scientists' calls for action on lowering emissions. A study by State Street Associates published in October 2021 found that there has been a "noticeable decarbonization trend globally" among institutional investor equity portfolios since 2019. And an April 4 report by the U.N.'s Intergovernmental Panel on Climate Change, or IPCC, sounded an alarm that greenhouse gas emissions must peak by 2025 and be reduced by 43% by 2030 if the

[1] This study was prepared and finalized before the U.S. Securities and Exchange Commission proposed amendments to its fund "Name Rule" and proposed new ESG disclosure requirements for investment companies on May 25, 2022.

[2] US SIF's total represents asset classes and investment vehicles beyond the equity mutual funds and ETFs used for this analysis.

SUSTAINABLE FINANCE

world is to hit net zero by 2050 and limit warming to 1.5° by 2100.

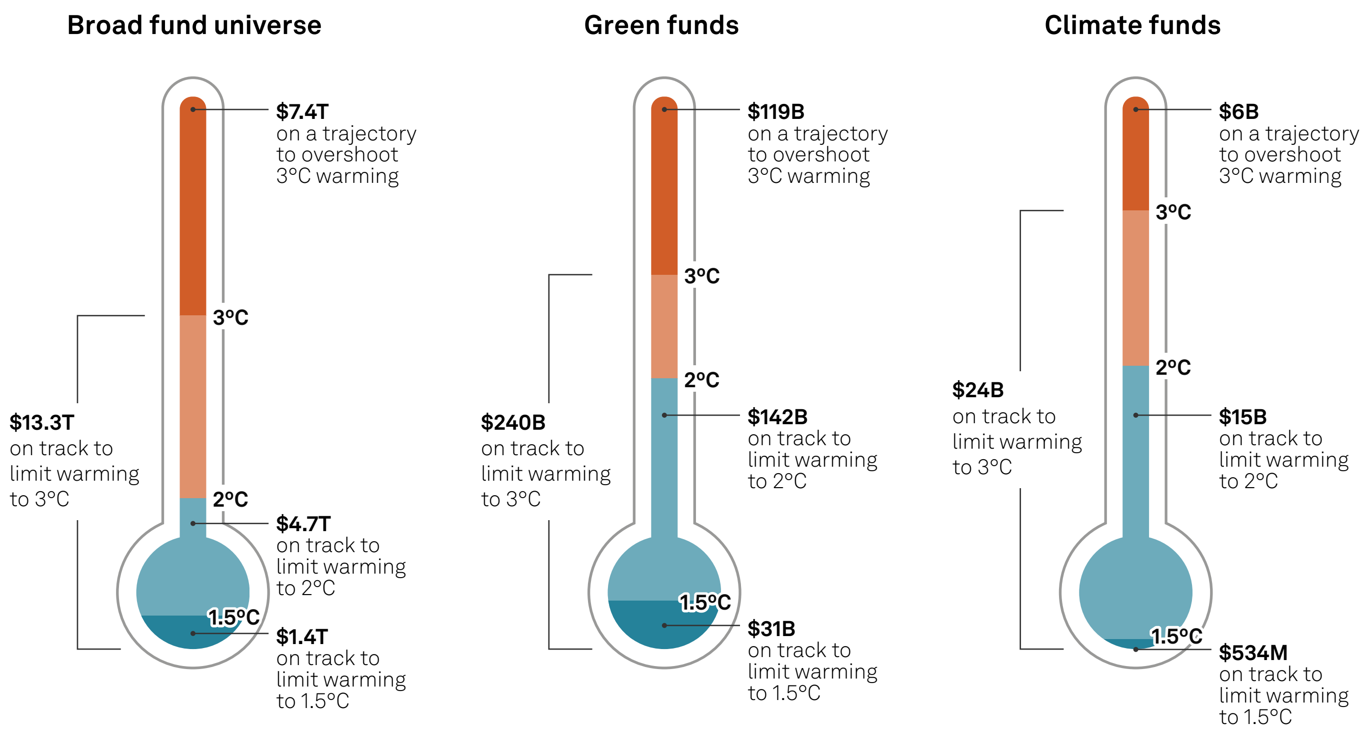
The consequences of missing the mark

Limiting the global temperature increase to the Paris Agreement's goal of roughly 1.5° above preindustrial levels is in theory the primary goal of any net zero or climate change-focused commitment. Even under this ambitious 1.5° scenario, the world still faces significant harm from climate change — coral reefs would decline as much as 90%, up to 14% of terrestrial species would face a very high risk of extinction and 40% of megacities globally would record a heat index higher than 105°F — but the world would stave off much greater losses to nature and human society, according to the IPCC's February 2022 report on climate adaptation.

Missing the Paris Agreement's "well below 2°" goal would put 10 million more people at risk from sea level rise and direct flood damage could be twice as high, according to the IPCC's adaptation report. At 3° of warming, disruption to ports and coastal infrastructure could impact entire financial systems, and risks to agricultural yields are 3x higher than at 2°.

Our analysis shows that 32% of the broad fund universe is poised to meet a 2° warming scenario, while 46% of funds are poised to overshoot even a less ambitious 3° warming scenario. The picture is slightly

One-third of market value in equity funds is not aligned with a 3°C scenario ($M)



Data as of April 19, 2022.
Analysis uses S&P Global Trucost Paris Alignment data to assess the difference between a company's projected pathway for Scope 1 and Scope 2 greenhouse gas emissions and the required pathway to reach alignment with three different goals from 2012 to 2025. The most ambitious is a goal of limiting warming to "well below" 2°C, or 1.5°C. The second is a goal of limiting warming to 2°C. The third and least ambitious is a goal of limiting warming to 3°C. Broad fund universe represents the full universe of 11,780 funds in this analysis. Green funds represent the 334 funds identified as using green language.
Sources: S&P Global Trucost; S&P Global Sustainable1

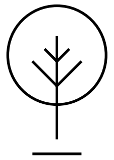
better for green funds: 39% of green funds are on track to meet a 2° warming scenario.

But 33% of green funds — over 100 funds representing close to $120 billion in market value — are on a trajectory to overshoot 3°. The same proportion of climate-specific funds — 17 out of 51 — are set to overshoot 3°. Fourteen green funds are more than 500 tonnes of CO_2e per $1 million invested over budget against a 3° pathway. These funds' names use terms including "climate change," "ecological" and "clean technology."

In terms of market value rather than number of funds, the green funds are somewhat better positioned than the broad universe. A greater share of green fund market value is aligned with 1.5° or 2°, whereas for the broad fund universe, a greater share of market value is aligned with 3° or above 3°. However, in both groups of funds, at least one-third of market value is on a trajectory to overshoot even a 3° scenario. In the narrower set of climate funds, market value is better aligned with 2°, but more than 20% of market value is set to overshoot 3°.

Patterns across scenarios

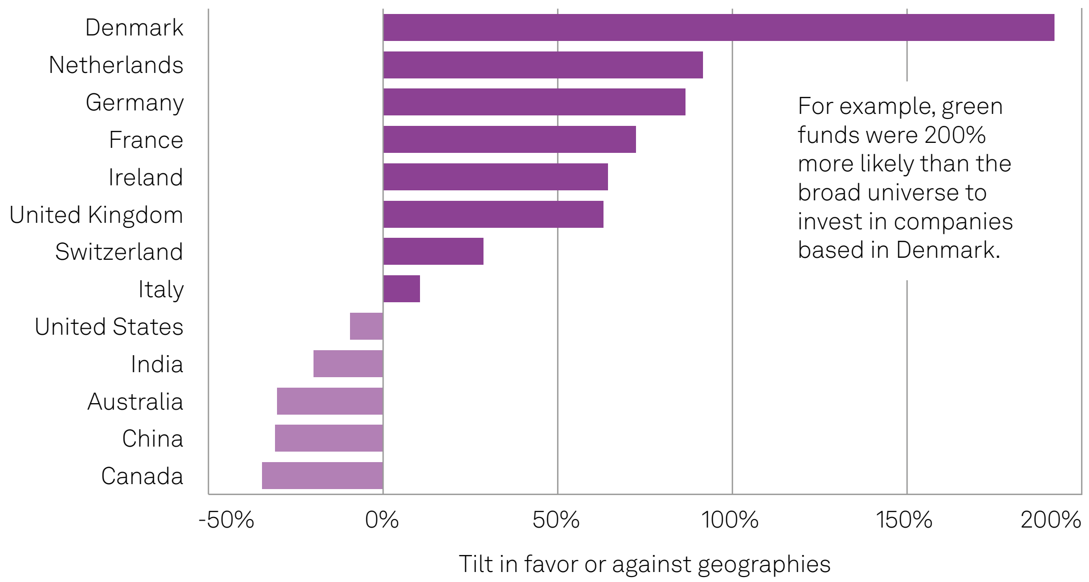
Each of the three scenarios in this analysis represents a different emissions budget, which reflects the level of global warming expected in the long term in that scenario. A 3° scenario has a larger emissions budget than a 2° scenario, which has a larger budget than a future limited to 1.5°. As expected, more funds in both the green-identified cohort and the broad fund universe are on track to meet a less ambitious 3° warming scenario. Yet in all three warming scenarios, at least one-third of green funds are over budget.



In all three warming scenarios, at least one-third of green funds are over budget.

Green funds invest relatively more in Europe

Geographic tilt of 334 green funds versus broad fund universe (%)



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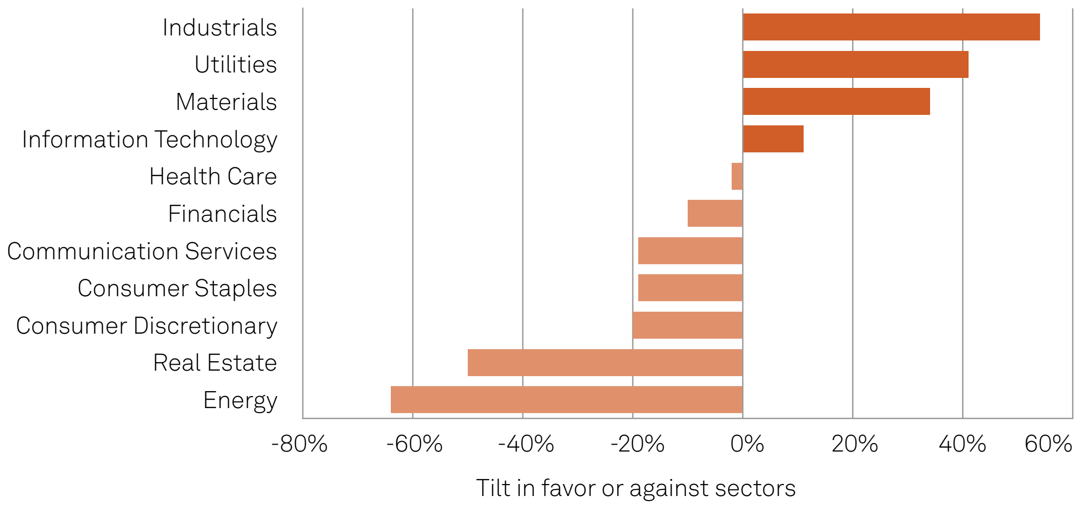
Sources: S&P Global Trucost; S&P Global Sustainable1

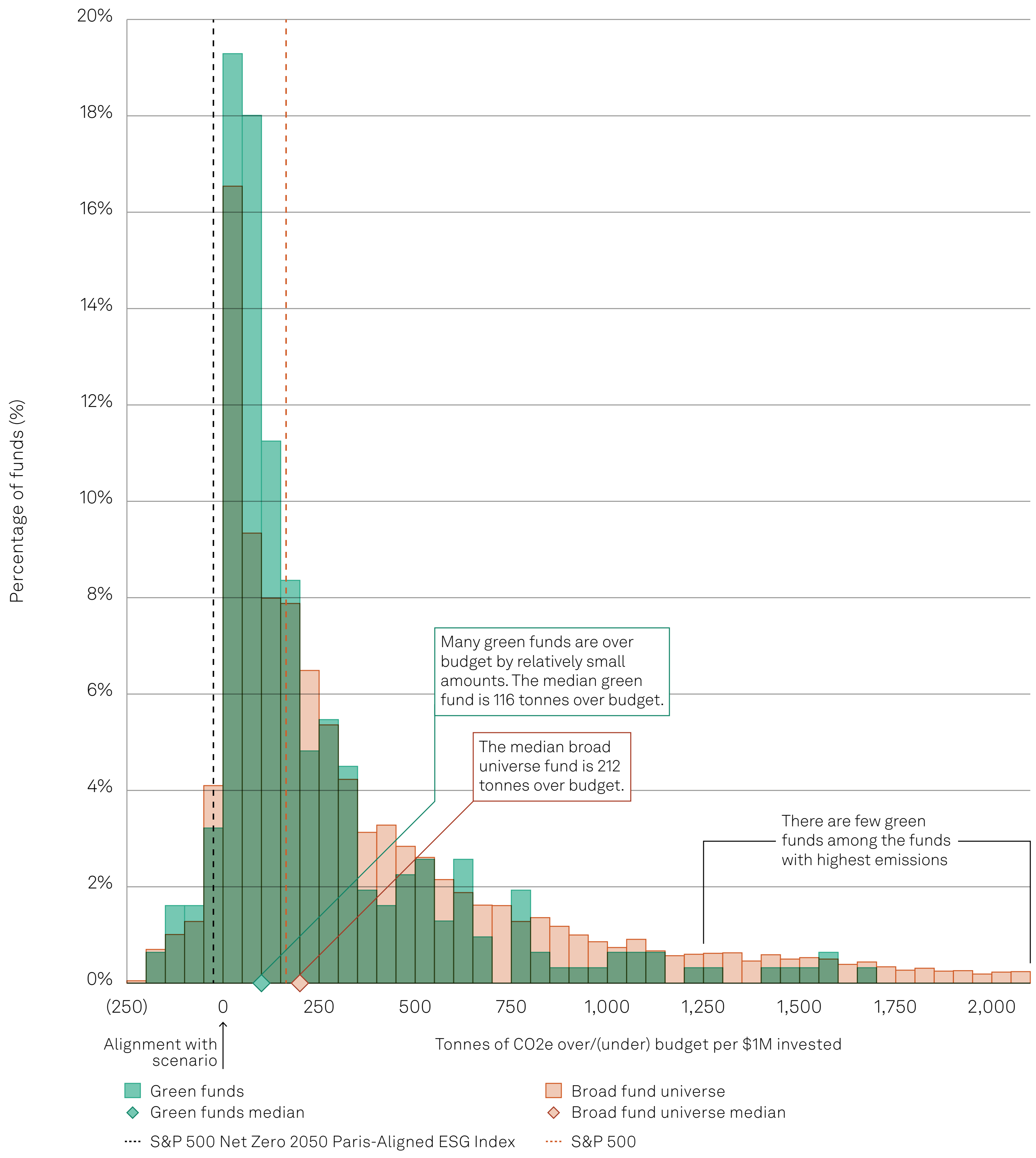
Green funds tend to be more overweight in industrials and utilities, and underweight in energy and real estate

Sector tilt of 334 green funds versus broad fund universe (%)



Data as of April 19, 2022.
Analysis uses S&P Trucost Paris Alignment data to assess the difference between a company's projected pathway for Scope 1 and Scope 2 greenhouse gas emissions, and the required pathway to reach alignment with three different goals from 2012 to 2025. The most ambitious is a goal of limiting warming to "well below" 2°C, or 1.5°C. The second is a goal of limiting warming to 2°C. the third and least ambitious is a goal of limiting to 3°C.
Sources: S&P Global Trucost; S&P Global Sustainable1

A higher percentage of green funds are near 1.5°C alignment than the broad universe of funds



Data as of April 19, 2022.
Analysis uses S&P Trucost Paris Alignment data to assess the difference between a company's projected pathway for Scope 1 and Scope 2 greenhouse gas emissions, and the required pathway to reach alignment with three different goals from 2012 to 2025. The most ambitious is a goal of limiting warming to "well below" 2°C, or 1.5°C. The second is a goal of limiting warming to 2°C. the third and least ambitious is a goal of limiting to 3°C. Outlers were excluded from this chart to improve visibility of the distribution.
Sources: S&P Global Trucost; S&P Global Sustainable1

The green funds over budget by the largest amount tend to be more focused on emerging and Asian markets, a finding consistent with the energy use and generation mix of fast-growing, industry-heavy countries. Yet there are also examples among the 10 most under-budget funds that focus on exposure to India and Asia, showing that Paris-aligned holdings are not in short supply in these regions. Green funds in the analysis tend to have more exposure to Europe and less exposure to China, Canada and the U.S. compared to the broad fund universe.

The green funds also tend to be overweight in the technology, materials, utilities and industrials sectors, and less exposed to the energy and real estate sectors, compared with the broad fund universe.

While a significant number of green funds are over budget in each scenario, they are generally closer to aligning with their budgets than the broad fund universe. A regression analysis shows that the emissions budget performance of green funds is statistically different from that of the broad fund universe.[3] The median green fund is much closer to being on budget in all three temperature scenarios than the broad fund universe. In the 1.5° warming scenario, for example, the median green fund is over budget by 116 tonnes of CO2e per $1 million invested, whereas the median of the broad fund universe is over budget by 212 tonnes of CO2e per $1 million invested — almost twice as much. Both the cohort of green funds and the broader universe are missing the Paris target, but green funds are closer to the mark. ■

[3] See the Appendix for more detail.

To continue reading and access the full report, please **click here.**

Conclusion

Companies are under pressure to understand their warming trajectory and plan accordingly to decarbonize. This same analysis can be extended to equity and mutual funds, which represent trillions of dollars of investments and play an important role in the energy transition of the broader economy. Our analysis points to a systemic issue — few funds, even those that describe themselves using green or climate-specific language, are on track to meet the goal of the Paris Agreement. Understanding the trajectory is an important step toward planning for a low-carbon future.

While our analysis shows that equity funds have a long journey ahead to meet the goal of the Paris Agreement, many misaligned funds are only slightly over budget: 116 of the over-budget funds in a 1.5° scenario are off by less than 100 tonnes of CO_2-equivalent per $1 million invested. By some measures, green funds are closer to alignment than the broad universe of funds. And dozens of funds in our analysis are under budget in all three warming scenarios, showing that Paris alignment is achievable — though alignment appears to be the exception rather than the rule.

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Appendix

Methodology: Fund selection

This analysis began with the universe of equity mutual funds and exchange-traded funds available on the S&P Capital IQ platform. From this universe, we identified 11,780 funds with a minimum market value of $5 million, with a minimum of 15 holdings, and for which at least 50% of market value is covered by Trucost Paris Alignment data. For the vast majority of funds, coverage is very high: more than 9,000 funds have coverage of 80% or higher.

To create a set of green funds, we searched fund names and descriptions as they appear on S&P Capital IQ for instances of more than 60 keywords or text strings related to renewable energy, sustainability, emissions, climate change and other green terminology in fund names and descriptions. The search results were manually vetted to remove false positives. Some funds in our final universe of 334 green funds do not limit their investments to green or environmentally focused companies.

To create a subset of climate funds, we searched fund names for keywords limited to climate, Paris, transition, carbon and net zero.

Methodology: Emissions

Our underlying metric of emissions in this analysis is tonnes of CO_2-equivalent above or below a company's budget, which is its allowable emissions forecasted through 2025 in a given warming scenario. After calculating the budget on a fund basis by apportioning the budgets of its holdings based on their size, we then divide by the fund's market value, measured in $M. This results in a final metric for this analysis of tonnes of CO_2e per $1 million invested.

$$E^m(f) = \frac{\sum_c E(c)w(f,c)}{V(f)}$$

The above means that emissions attributed to fund *f* are computed as the sum of the emissions of each of its constituents, weighted by *f*'s share of ownership in each constituent *c*, and finally normalized by the fund's value *V(f)*. The resulting measure is the number of tonnes of CO_2e above budget (or below budget, if negative) for each $1 million invested in fund *f*.

Statistical analysis

To measure the significance of the difference in emission budget over/under values across the group of green funds and the non-green funds in the broad fund universe, we run the following regression. We find that the variable of whether a fund is in the group of green funds has statistical significance, but also that its significance is similar to another variable: a fund's investment style.

$$scoreQ(f) \sim 1 + efund(f) + totVal(f) + style(f)$$

We regress the percentile that fund *f* belongs to *scoreQ(f)* on a constant variable indicating if the fund is green, on the fund's market value and on the fund's style. The results for quantiles computed for the 1.5° temperature scenario, below, are representative of all three scenarios. The fund style "aggressive growth" is used as the baseline.

The green fund variable coefficient is negative and statistically different from 0, suggesting that membership in the green fund group does matter. Notably, most investment style coefficients are larger in absolute value than the green funds' coefficient, suggesting that the style label is more correlated with emissions than membership in the green funds group.

		Coefficient	T-statistic	P-value
	Intercept	38.788	34.451	1.18340E-247
	Fund market value	-1.16E-05	-0.70273	4.82240E-01
Fund investment styles	Blend	16.114	11.505	1.82500E-30
Fund investment styles	Deep value	3.897	2.226	2.60320E-02
Fund investment styles	Growth at reasonable price (GARP)	24.903	19.829	4.51610E-86
Fund investment styles	Growth	5.4206	4.5599	5.16960E-06
Fund investment styles	Unclassified style	24.841	5.9813	2.27860E-09
Fund investment styles	Value	24.995	15.642	1.37290E-54
	Green fund	-6.4082	-3.9157	9.06460E-05
	Number of observations	11,550		
	Root mean squared error	29.4		
	R-squared	0.0909		
	Adjusted R-squared	0.0903		
	F-statistic versus constant P-value	2.79E-232		

The size of the fund is shown to not be statistically significant.

Geography and sector tilt

The tilt used in the sector and geography exposure charts is defined as follows:

$$T(s) = 1 - \frac{\sum_{f \in G} V(f,s)}{V^G} \Big/ \frac{\sum_{f \in NG} V(f,s)}{V^{NG}}$$

$\sum V(f,s)$ is the sum of the value invested into sector or geography s by the green funds $(f \in G)$. $VG = \sum_{f \in G} V(f)$ is the overall value of the green funds, so their ratio is the percentage invested into *s* by the green funds. The NG figures represent the same quantities for the non-green funds. Therefore, *T(s)* equals 1 if green and non-green funds *as a whole* invest the same percentage of their value in sector *s*. *T(s)* is less than 1 if the green funds as a whole are underweight in *s*, compared to the non-green funds.

Emission scopes

Importantly, our analysis only includes Scope 1 emissions, those created by company operations, and Scope 2 emissions, generally those associated with any electricity a company purchases. This analysis does not include Scope 3 indirect emissions, which occur in the supply chain — including when customers use the products or services the companies provide. Scope 3 emissions are disclosed by far fewer companies, and ranges of modelling error are likely wider than in modelling Scope 1 and Scope 2. For this reason, S&P Global excludes Scope 3 from Paris Alignment assessments to limit the chances of mistaken inferences.

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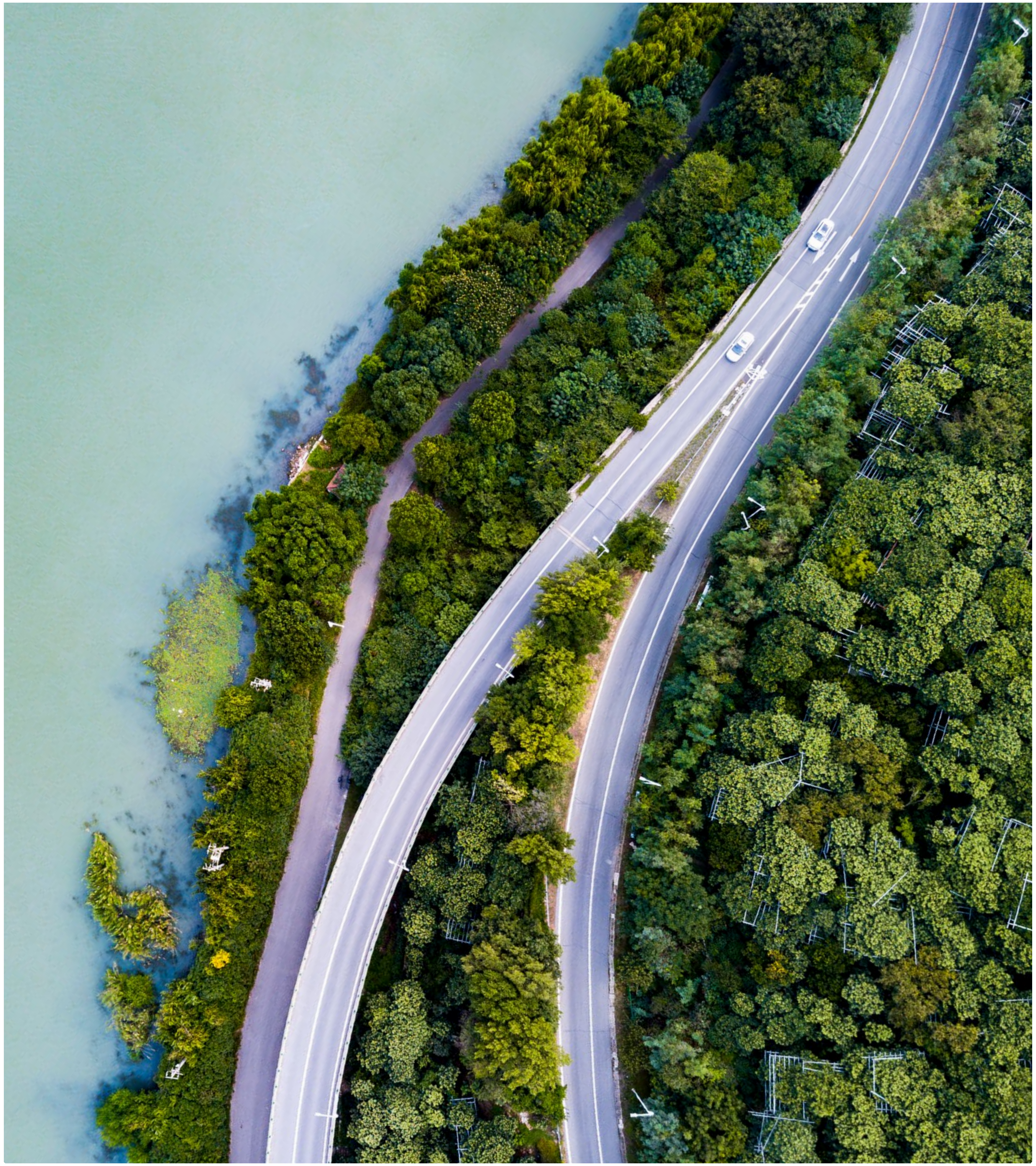


Carbon pricing, in various forms, is likely to spread in the move to net zero

Government policies seeking to transition economies to net zero emissions are likely to increase globally amid the urgency of mitigating climate change impacts. These are likely to include some form of carbon pricing, which many economists view as one of the most efficient policy levers to encourage emissions reductions. While relatively few carbon pricing frameworks are in place at present, S&P Global expects more countries to adopt some form of carbon pricing as part of broader policy mixes as the world moves to mitigate global warming.

Published on Aug. 9, 2022

This research paper draws on the research and insights of S&P Global Ratings, S&P Global Commodity Insights, and S&P Global Sustainable1. It does not comment on current credit ratings nor does it constitute a methodology used for credit ratings.

This report does not constitute a rating action.

Key takeaways

- Government policies seeking to transition economies to net-zero emissions are likely to increase globally, amid the urgency of mitigating climate change impacts. These are likely to include some form of carbon pricing regulations, one of the policy levers that we have observed being used by some governments as they aim to achieve emissions abatement targets. Many economists argue that carbon pricing policies are one of the most efficient policy levers to encourage reductions of GHG emissions. From an economic perspective, they provide direct incentives for households and firms to account for the environmental cost of carbon emissions.
- Relatively few carbon pricing regulations are currently in place, covering less than a quarter of global GHG emissions. The largest carbon markets by emissions coverage are found in the EU and China, and others are in place in the U.K., Canada, select U.S. states and Asia, among others.
- The EU's carbon price is about €80/tCO_2e today, supported by its Fit for 55 environmental package and impetus from the Russia-Ukraine conflict and related energy crisis. We expect the EU's carbon allowance prices to exceed €100/tCO_2e from 2025 onward, as the EU steps up its transition to net zero.
- Political and economic considerations, like affordability, are more conducive to gradual, localized applications of carbon pricing policies, rather than a drive toward a single global carbon price.
- Sectors such as utilities, materials, energy and transportation are among the most carbon intensive on a direct emissions basis. Companies better prepared to deal with higher carbon prices may enjoy greater optionality to adjust their businesses and a stronger competitive position.
- For the rest of 2022, further developments in the Russia-Ukraine conflict are likely to impact emissions from the EU power sector, as member states seek to extend more polluting coal-fired generation and LNG imports capacity to meet short-term demand, in response to potential restrictions of Russian oil and gas imports. For EU countries in particular, ambitious decarbonization objectives will continue to be managed against other priorities such as energy security and affordability.

▶ **Over time, we think a greater number of** countries will likely adopt some form of carbon pricing policies as part of broader policy mixes to reduce greenhouse gas emissions to mitigate global warming. Here, we survey the existing policies in place, which today cover less than a quarter of global GHG emissions. Those policies are varied in scope and geography, and we do not expect to see a single global carbon system or price in the near future.

We take a look at the EU's emissions trading system, or ETS, one of the world's most established. Discussions are proceeding among member states to increase its scope and institute a carbon levy at the border to tighten the regime and reduce regulatory arbitrage. We expect the EU's carbon allowance prices to increase and exceed €100/tCO_2e (tonnes of CO_2 equivalent) from 2025 onward, as the EU steps up its transition to net zero.

Looking ahead, this paper also briefly looks at sectors with higher direct emissions, which is only one indicator. Others include the ability to substitute or compete with less carbon-intensive products or to pass on the cost to their end clients. Assuming a future with an increased number of carbon pricing policies, it seems clear that companies with a greater ability to adjust their business models and operations will be less exposed — and perhaps better able to compete. Over time, investor demand for climate-related disclosures from companies is likely to increase. In 2017, the Task Force on Climate-related Financial Disclosures (TCFD) published recommendations in this area.

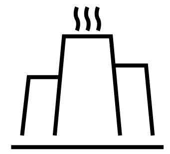
The state of the world's carbon pricing policies

Governments and policymakers have a wide range of instruments at their disposal to mitigate global warming and have taken steps to use them (see "Green Spending Or Carbon Taxes (Or Both): How To Reach Climate Targets, And Grow Too, By 2030?" published by S&P Global Ratings on Nov. 4, 2021). For example, green spending has increased — even during the COVID-19 pandemic. Plus, several central banks have adopted a supervisory approach to raise awareness and monitor climate-related risks in the financial sector (see "Central Banks And Climate Change," June 16, 2022). And then there's carbon pricing, which many economists argue is one of the most efficient policy levers to encourage reductions of GHG emissions. They argue that because carbon emissions are a negative externality linked to consumption or production patterns, not well accounted for by economic agents, they don't carry any direct cost unless taxed or priced by a market mechanism. So far, the use of carbon pricing policies remains relatively modest across the globe.

For the purpose of this research, we define carbon pricing policies to mean either the implementation of a carbon taxation regime or establishment of a compliance-based carbon market (such as an emissions trading system, or ETS). These are examples of direct carbon pricing. Indirect carbon pricing includes, for example, taxes with implied carbon costs — such as fuel taxation or outright bans on polluting products, like bans on fossil fuel-powered cars.

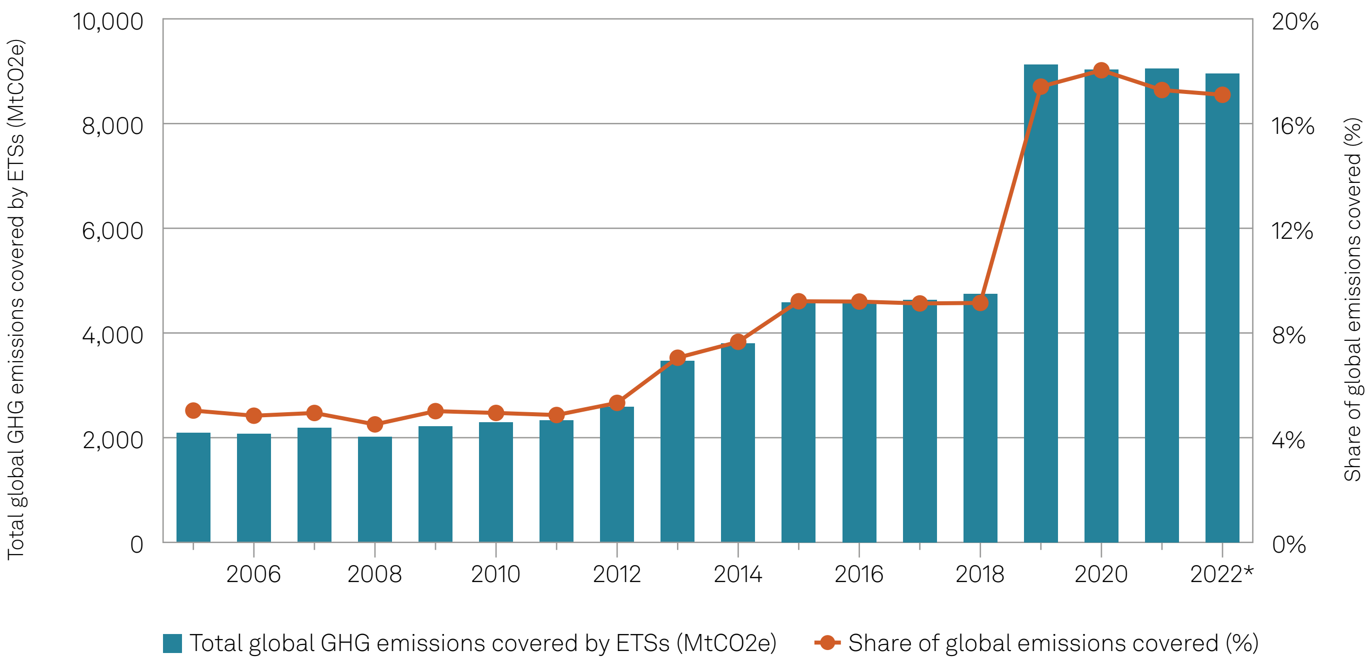
In an ETS, the governing body sets a total quota of emissions permitted for the year for all participating sectors. Participating companies are required to acquire and surrender emission "allowances" (emissions permits) to cover their annual emissions to the regulating authority or face a penalty for every allowance not surrendered. Allowances can be auctioned to the highest bidder as well as traded on secondary markets, creating a carbon market with a price set by the market itself. Companies whose emission abatement efforts are financially more costly than others purchase these allowances from the ETS market, while companies that can reduce their emissions may sell surplus allowances to other participants. Policymakers may adjust the quota of emission allowances in a market system or the sectors included in the ETS to indirectly control the allowance price.

Around 17% of global GHG emissions were covered by ETSs as of 2021, up from about 5% when the EU ETS system was established in 2005, according to the International Carbon Action Partnership (ICAP). ETS and carbon taxation policies combined covered around 23% of global emissions as of April 2022, according to the World Bank's report, "State and Trends of Carbon Pricing 2022, World Bank," May 24, 2022.



Around 17% of global GHG emissions were covered by emissions trading systems as of 2021, up from about 5% in 2005.

Chart 1: **Global expansion of GHG emissions covered by emission trading systems**



*As of March 2022. Note: The sharp increase in 2019 reflects the start date of the Chinese National ETS in 2021, while also indicating the retroactive coverage of the system in 2019 and 2020. For further details on ICAP's methodology see "Emissions Trading Worldwide: 2022 ICAP Status Report," March 2022.
MtCO2e--Metric tons of carbon dioxide equivalent.
Source: International Carbon Action Partnership (2022).

Carbon markets take different forms globally, with state and provincial schemes most prevalent

In its May 2022 publication, the World Bank reported 34 different ETSs implemented around the world. The majority of these schemes are operating at the subnational level in the North American and APAC regions. One spans a multinational area — the EU ETS. In the U.S., a number of state-level cap-and-trade systems have been established since 2013, with the largest being California's, which is currently linked to the Canadian province of Quebec. A federal approach to carbon pricing regulations in the U.S. does not exist, and we do not foresee the establishment of one in the near term given the political and macroeconomic environment.

China launched its national ETS in 2021, which initially applied to emissions from the power sector and was backdated to cover emissions from 2019 and 2020 in its first compliance phase. Unlike other ETSs, China's sets an intensity target-based cap, rather than an absolute cap on annual emissions. China plans to gradually roll out its ETS to additional sectors over the next few years and has expressed a strong commitment to reducing its carbon emissions.

The EU ETS is the longest running of such systems in the world, first launched in 2005. The EU ETS applies to emissions from the power sector, heavy industry (including but not limited to steel, cement, and chemicals production) and intra-EEA aviation. The scheme is currently in its fourth phase, which runs from 2021 through 2030.

The economic and redistributive impacts of carbon pricing policies are a hurdle to implementation

Where they exist, we observe that carbon markets have to date not resulted in carbon prices that are high enough to incentivize a reduction in emissions in line with climate ambitions pledged by the countries with carbon pricing regulations. The OECD uses €120 per tonne of CO_2 as an estimate of the price needed in 2030 to decarbonize by midcentury and finds that in 2018 only 12% of emissions in its member countries were priced at that level. That's despite many of these countries targeting net zero by 2050. Some jurisdictions have also protected carbon-intensive industries from potential losses in cost competitiveness because of carbon pricing through the issuance of free emission allowances (for example, in the EU ETS). This reduces the implied cost of carbon for those emitters, making those schemes arguably less effective at achieving emissions reductions.

Hurdles to implementation include concerns regarding potential weakening of consumer purchasing power and business competitiveness, as well as concerns about social equity. Depending on how carbon pricing regulations are designed, they can have immediate visible repercussions for the end-consumer. Because companies generally pass on the costs, consumers tend to pay the price. Companies selling their products in international markets might also suffer from lower cost competitiveness than nonregulated peers, although the evidence on this phenomenon is somewhat mixed. For governments, developments in the energy market, such as gas supply shortages and higher fuel and power prices currently driven higher by the Russia-Ukraine conflict, are creating tough choices about how to balance immediate energy security needs and affordability with longer-term energy transition plans.

To illustrate the different macroeconomic implications of carbon pricing, we ran a carbon tax scenario assuming a gradual increase in the carbon price for all sectors of the economy to $100 by 2030 in the U.S., China and the EU. (Note that carbon prices achieved through an ETS do not cover the whole economy as they do not apply to all sectors.) Our results, originally published in November 2021, highlight that given China's larger reliance on carbon-intensive energy sources, the economic impact could be much larger than in the U.S. or the EU, all other things being equal. Our scenario points to an 8% GDP loss by 2030 for China, compared with much less for the U.S. at 3% of GDP and the EU at 2% of GDP (see chart 2). For the EU, the impact is relatively muted given it has already embarked on the green transition and the existing carbon price is higher there than in the other jurisdictions (see "Green Spending Or Carbon Taxes (Or Both): How To Reach Climate Targets, And Grow Too, By 2030?" Nov. 4, 2021).

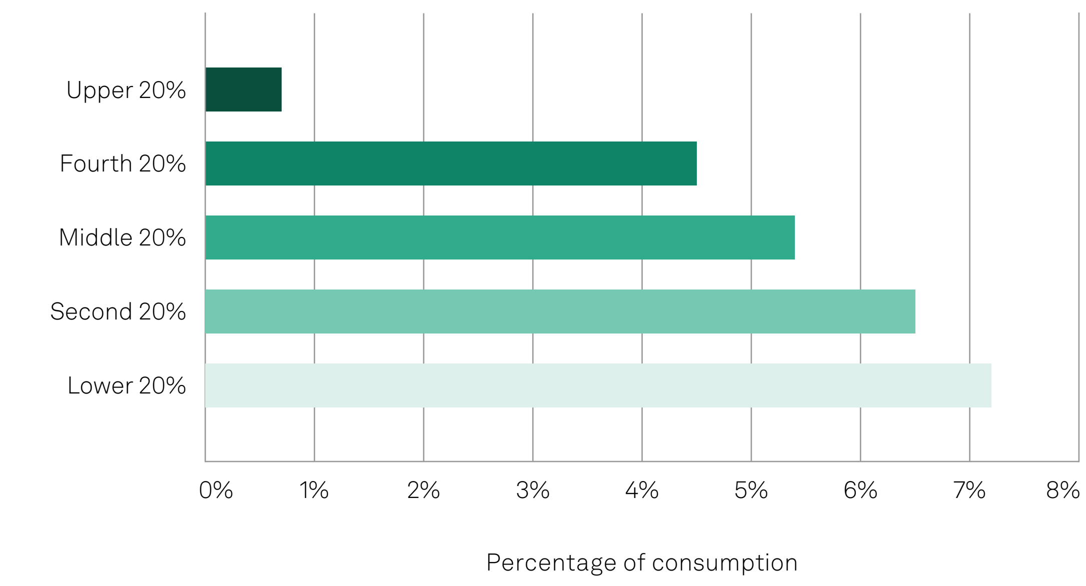
Our research also highlights that lower-income households (see chart 2) and smaller firms tend to lose relatively more from these types of mechanisms as they spend a larger share of their revenues on energy and have less capital to invest in energy efficiency. These distributional consequences suggest that carbon pricing is unlikely to be implemented as a single measure to encourage emissions abatement.

To offset some of these redistributive consequences and potential economic losses, one option could be to reuse any carbon tax or program proceeds for household income support or to finance investments, as chart 3 shows. For example, the European Green Deal and the Fit for 55 package actively seek to address these effects with redistributive funds, such as the Just Transition Fund, the Social Climate Fund, and targets for energy efficiency and renewable energy that will require investment.

Hurdles to implementation include concerns regarding potential weakening of consumer purchasing power and business competitiveness, as well as concerns about social equity.

CARBON PRICING

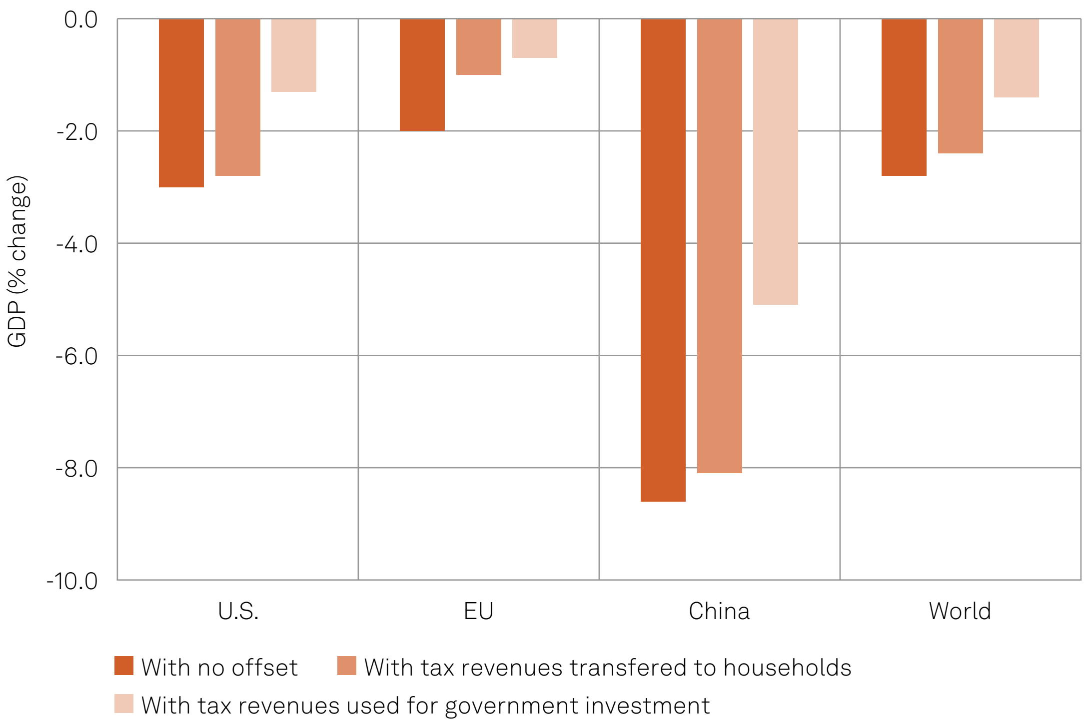
Chart 2: **Less affluent households are more vulnerable to energy taxes**



Sources: Eurostat, S&P Global Ratings.

Chart 3: **Raising the price of carbon to $100 by 2030 is likely to weigh on GDP in most countries**

GDP impact of a $100 a ton carbon tax by 2030 (difference to business-as-usual baseline)



Note: We note that these are rough estimates because such a big macro model is unlikely to fully capture some of the complex environmental dynamics, in particular for China, where the data is less rich than for the U.S. and EU.
Sources: Author's calculations using Oxford Economics Global Economic Model, S&P Global Ratings.

Carbon pricing regulations are likely to spread as more countries move to mitigate climate change

Despite implementation challenges, we think more carbon pricing policies are likely to be included as part of broader policy mixes as many countries continue to strengthen their climate commitments. The recent IPCC report, "Climate Change 2022: Mitigation of Climate Change," alerted the world that "limiting warming to around 1.5 degrees Celsius requires global GHG emissions to peak before 2025 at the latest," while last year's Glasgow COP26 conference explicitly stipulated the need for annual follow-up and revisions to the targets. Although it is difficult to anticipate what kinds of policies jurisdictions might adopt to reduce their carbon emissions, we believe the number of carbon pricing policies is likely to increase and think they will be included as part of larger policy packages to green the economy. If these policies are implemented effectively in otherwise functioning markets, many economists argue that direct or indirect carbon pricing can help firms and households incorporate the cost of pollution in their choices, which is otherwise an externality that they don't see (as any Pigouvian tax that seeks to price a negative externality generated by market transactions), and incentivize a reduction in emissions.

The EU, one of the few jurisdictions that has explicitly announced its objectives for greening its economy, provides a detailed roadmap for emissions abatement and transition policies. The EU Commission released plans in July 2021 to reform the EU ETS and a carbon levy at the border (the carbon border adjustment mechanism, or CBAM), which could trigger more carbon pricing across the world.

The CBAM intends to avoid regulatory arbitrage known as "carbon leakage" and put an end to free allowances under the EU ETS, which were issued to alleviate competitiveness concerns, but have undermined the effectiveness of the ETS to date. The European Parliament's recent vote on the Fit for 55 package favors a phasing out of free allowances between 2027 and 2032 and starting the gradual implementation of the CBAM. Some jurisdictions affected by the CBAM may consider domestic carbon pricing policies to avoid a disruption in trade and keep carbon tax revenues at home, especially those countries with strong trade links to jurisdictions that introduce carbon pricing at the border.

Direct or indirect carbon pricing could help firms and households incorporate the cost of pollution in their choices

For jurisdictions currently without a carbon pricing policy in place, wide differences in political preferences and wealth globally suggest they are likely to take a variety of approaches to reducing carbon emissions. The hurdles highlighted above suggest that we are more likely to see an increase of a variety of different carbon pricing policies, that is, predominantly localized initiatives to price some carbon emissions, rather than a global carbon price covering all sectors. In addition, we think carbon pricing, which is one of several instruments at policymakers' disposal, where adopted is likely to be combined with other measures to green economies. For example, investment in cleaner production processes — like improving the energy efficiency of buildings — or encouraging consumers toward more sustainable lifestyles through behavioral policies — by raising awareness about climate change and the environmental impact of their purchases — can also contribute to reducing carbon emissions.

Central EU carbon price forecasts and drivers, from S&P Global Commodity Insights

Here, S&P Global Commodity Insights provides its price forecast for the EU ETS, the world's most established carbon market framework, launched in 2005.

We expect the EU carbon price to increase to, then exceed on a sustainable basis €100/tCO_2e by 2025, up from around €80/tCO_2e today

The EU ETS carbon allowance price (EUA) has recovered following a period of high volatility after the outbreak of the Russia-Ukraine conflict to trade around €80/tCO_2e. This is in line with our monthly average EUA price expectations. The recovery and stabilization of the EUA price have been supported by demand for allowances from compliance entities at auctions and continued hedging interest amid ongoing negotiations about reforming the EU ETS, due for implementation next year.

For the rest of 2022, we expect the Russia-Ukraine conflict to have significant impact on emissions from the EU power sector, as member states seek to extend more polluting coal-fired generation and LNG imports capacity to meet demand in response to potential sanctions imposed over Russian oil and gas imports. As a result, we forecast the region's annual power emissions to increase by 3% in 2022. While this may have bullish implications for EUA prices, rising power sector emissions may be offset by diminishing demand from industrial participants, in response to the ongoing impact of high energy prices. On July 26, 2022, EU member states agreed to a voluntary 15% gas demand reduction between August 2022 and March 2023.

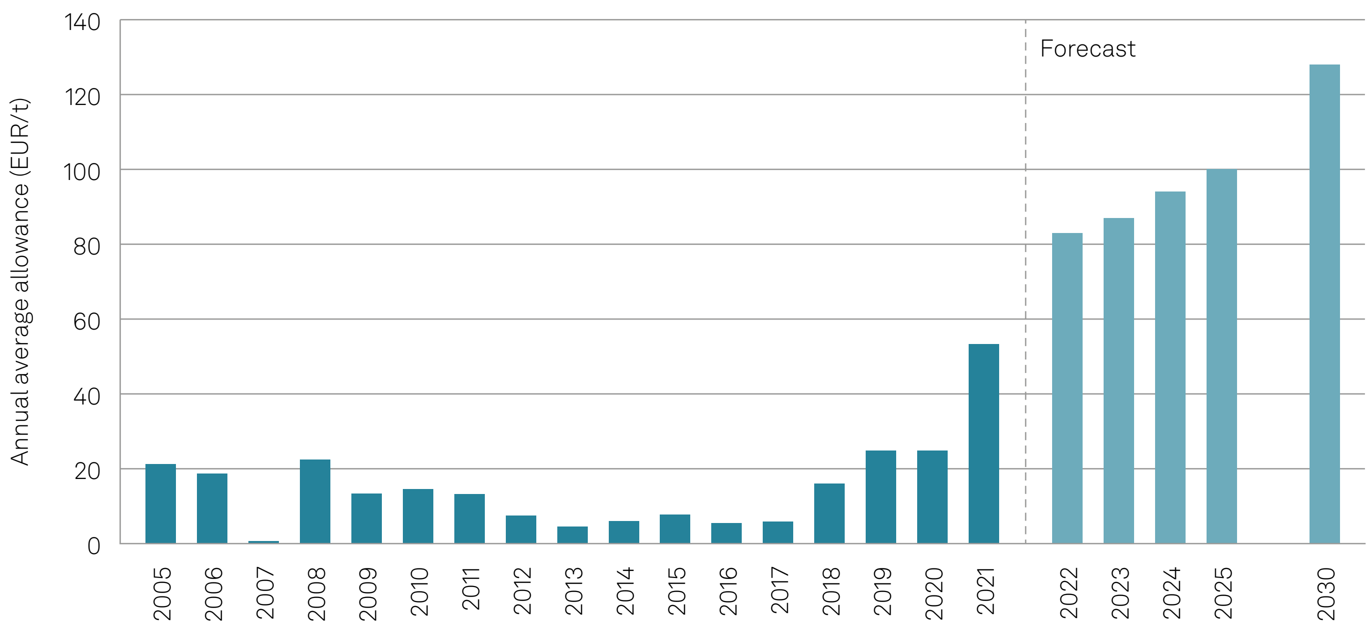
Our EUA price forecast currently does not fully account for a bearish risk of significant demand destruction from EU industrial installations in 2022. The probability of a global recession has risen, but this is not currently our baseline.

Following the implementation of policy reforms currently being negotiated by EU legislators as part of the Fit for 55 package, our view is for nominal EUA prices to increase and exceed €100/tCO_2e annually by 2025. We forecast tighter balances of allowances in the system as a result of policy reforms, which initially will support greater investor interest in trading EUAs during the current phase until 2030. Higher investor demand, coupled with demand for allowances by sectors with current or future compliance obligations, will support higher EUA prices beyond fuel-switching prices through the mid-2020s. While this is a significant increase in the price of carbon for EU economies, we note this will not apply to all sectors, so the price of carbon for the aggregate economy is likely to remain below the €120 mark used by the OECD, unless other measures are taken to price carbon for other sectors not covered by the ETS.

Beyond this, we expect that the EU will prepare and publish further plans for policy revisions of the EU ETS in anticipation of the fifth phase of the scheme that starts in 2031. Deeper emissions reductions are required from 2030 from the harder-to-abate industrial and transportation sectors, as low-cost fuel switching in the power sector is mostly exhausted. As such, we expect higher industrial abatement costs to decarbonize the industrial and transportation sectors and set the EUA price in the long term.

Chart 4: **S&P Global Commodity Insights current forecasts for EUA prices**

We forecast continued strength in EUA prices with alignment to EU Fit for 55 targets



Source: S&P Commodity Insights' published forecasts for EUA prices.

We expect the EU ETS to evolve, expand, and tighten as early as 2024

As we mentioned above, the EU ETS is being reformed as part of its wider Fit for 55 package. The European Commission plans to significantly strengthen the climate ambition of the EU ETS, to ensure its climate trajectory is consistent with the EU's legislated 55% emissions reduction target below 1990 levels by 2030. Reform proposals are currently under review by member states and the European Parliament. We expect the review will end in early 2023, followed by implementation of legislation by the end of 2023.

Policy proposals, including plans to expand the scope of the EU ETS to maritime emissions and reduce the cap on emissions, started to raise EUA prices in July 2021. We expect further price uplift later this year as final policy designs are agreed, likely to come from existing and new sectors to EU ETS looking to build their allowance balances in advance of legislative changes to the EU ETS taking effect, to manage effects on long-term cash flow.

Our longer-term EUA price forecast is subject to future policy revisions by the EU and any further policy responses to the Russia-Ukraine conflict. The EU released its REPowerEU plan on March 8, seeking to accelerate development of renewable energy production and accelerate the roll-out of domestic heat pumps to improve energy efficiency. REPowerEU could provide short-term uplift to EUA prices through to 2030 via increased energy demand, but dampen annual increases from 2030 as demand lessens from power sector participants.

CARBON PRICING

Relative to revenue generation, we find that utilities, materials, energy and transportation are among the most carbon-intensive sectors on a direct emission basis.

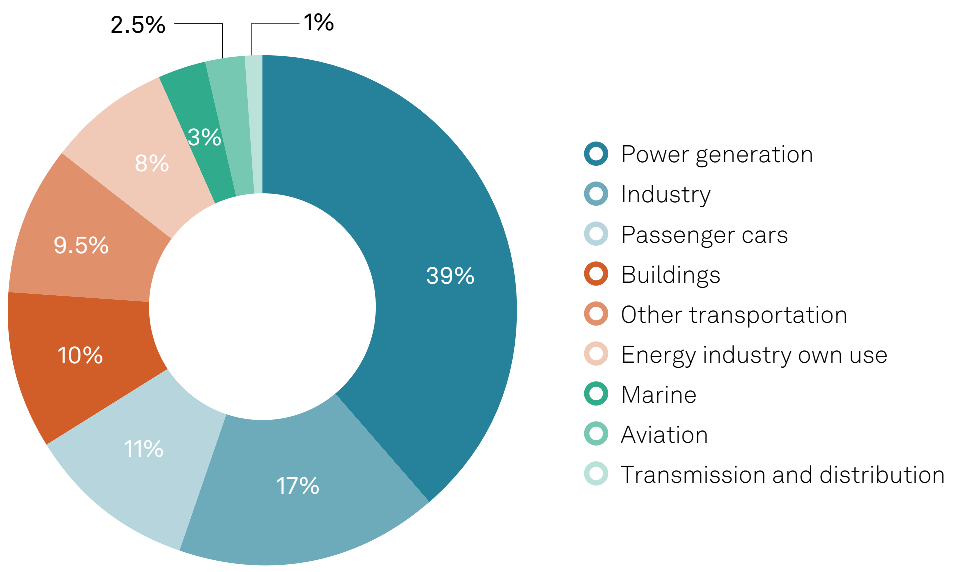
What sectors have the highest emissions?

The heaviest-emitting sectors are most likely to be subject to carbon pricing and, in turn, bigger increases in costs linked to their carbon emissions. Platts Global Integrated Energy Model from S&P Global Commodity Insights forecasts that power generation will remain the biggest source of global CO_2 emissions for 2022, followed by emissions from industry and transport sectors (see chart 5). The majority of existing ETSs already covers emissions from at least the power sector or heavy industrial sectors, but few cover transport, with international aviation emissions covered only within the EU, U.K. and Swiss ETSs. Historically, in some schemes, power and heavy industry have been offered a degree of protection from full exposure to a carbon price. The main reasons are to reduce the risk of carbon leakage — that is, companies moving production to jurisdictions with no carbon pricing — preserve cost competitiveness and manage the transition toward a low-carbon economy.

Relative to revenue generation, we find that utilities, materials, energy and transportation are among the most carbon-intensive sectors on a direct emission basis. This suggests that their businesses are more exposed to increases in carbon pricing than other sectors (see chart 6). We note that this does not necessarily provide the full picture for energy transition risks for all sectors, since this data and our report only address direct or Scope 1 emissions, given that this has been the primary focus for most jurisdictions. When considering an organization's overall exposure to energy transition risks, Scope 2 and Scope 3 emissions can also provide useful information.

Chart 5: **Expected breakdown of Global CO_2 emissions by direct combustion for 2022 (%)**

Our Global Integrated Energy Model Forecasts majority of global emissions to come from power generation sector



Source: Platts Global Integrated Energy Model by S&P Global Commodity Insights.

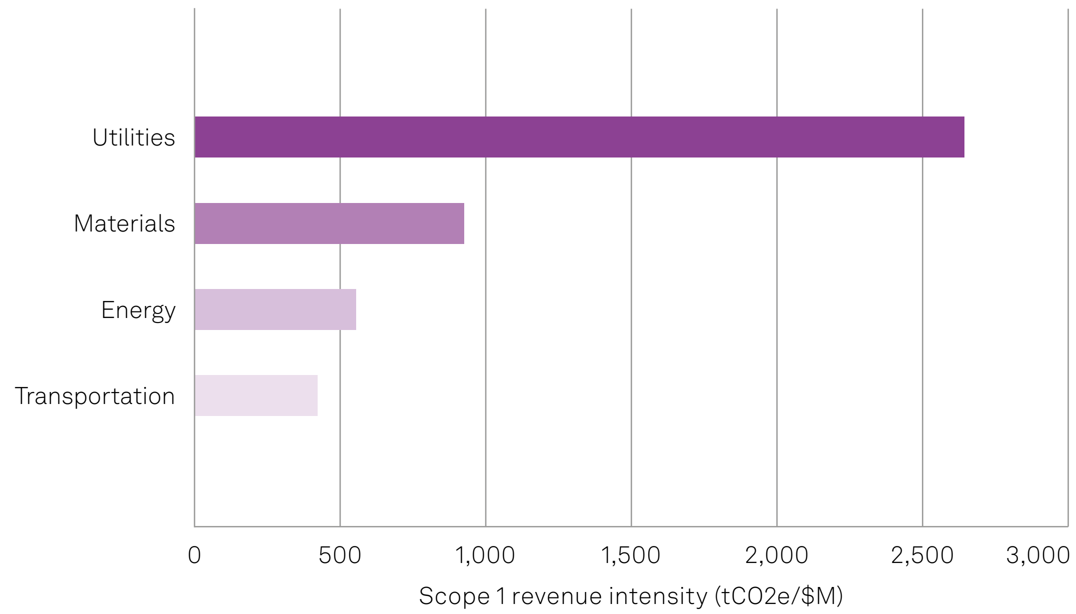
What emissions intensity could mean for competitiveness

We note that high direct emissions intensity cannot be taken as the sole indicator of the future potential financial materiality of carbon pricing for a sector or its future competitiveness. For example, it is likely that companies in industries where there are no or limited substitutes or competing products might be able to pass a meaningful portion of the cost of carbon pricing to their end customers.

As the scope of regulation expands and carbon emissions-related costs potentially become financially more material, we believe this could translate into a competitive advantage for companies that have successfully lowered their emissions. Even if one cannot predict the actual future cost of carbon as policies evolve, companies with a greater degree of preparedness should be able to have greater optionality to adjust their business models and operating processes and be less exposed to potential carbon pricing or penalties than the less prepared ones. Although the magnitude of financial impact might differ from one sector to another, which does not just depend on emissions exposure but as much on prevailing regulations and pass-through of carbon costs to consumers, we would expect some companies will need to engage in substantial and long-term capital expenditure projects to reduce emissions intensity.

Some companies will need to engage in substantial capital expenditure projects to reduce emissions intensity

Chart 6: **Top 4 sectors: Scope 1 emissions revenue intensity per tonne**



Note: Scope 1 revenue intensity is calculated as tons of Scope 1 emissions per $1 million of revenue. Calculation is based on 2019 and 2020 averages using GICS Industry Group data. The analysis is based on companies covered by S&P Global Trucost (a part of S&P Global Sustainable1) in its Trucost Environmental dataset.
Source: S&P Global Sustainable 1.

CARBON PRICING

Meanwhile, we don't believe that every company will enjoy the same starting level of access to capital markets and technology. Businesses in wealthier countries generally enjoy stronger access to capital markets, which should help them proactively modify their energy mix and products as well as finance the sizable capital expenditure associated with investing in new technologies or emission-abatement projects, as long as a sound strategic plan is in place. However, some businesses in developing markets might not have the same access to capital markets or technology. ■

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- State and Trends of Carbon Pricing 2022, World Bank, May 24, 2022
- Emissions Trading Worldwide: Status Report 2022, International Carbon Action Partnership, March 2022

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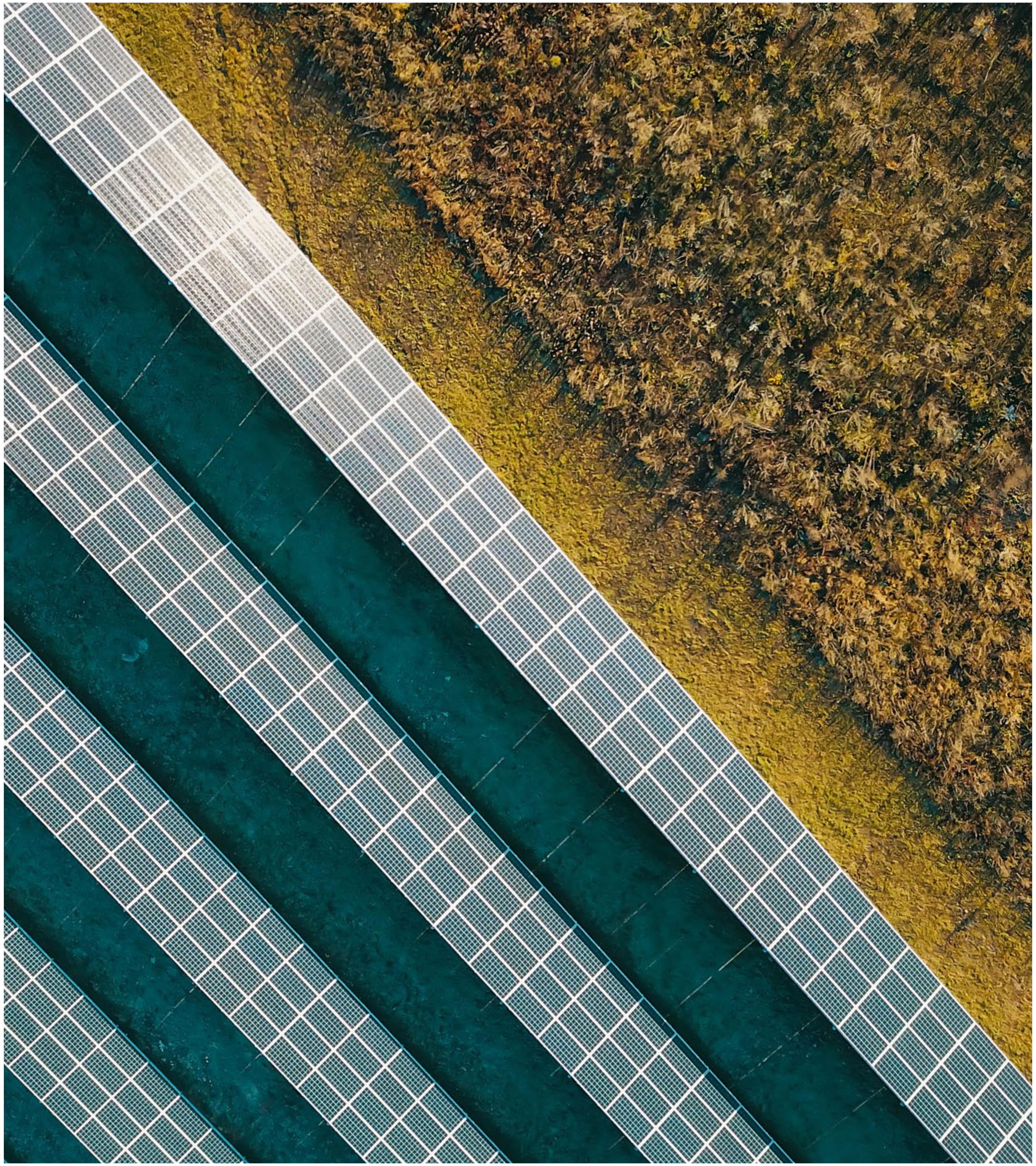


Energy transition:
Renewables remain the cornerstone of future power generation

The heightened urgency of the climate crisis has accelerated calls for the global energy industry to shift from fossil-based systems of energy production and consumption — including oil, natural gas, and coal — to renewable energy sources. But as research from S&P Global Commodity Insights shows, accelerating the expansion of renewables generation, in line with limiting global warming to less than 2°C per year, would require significant additional momentum beyond market economics.

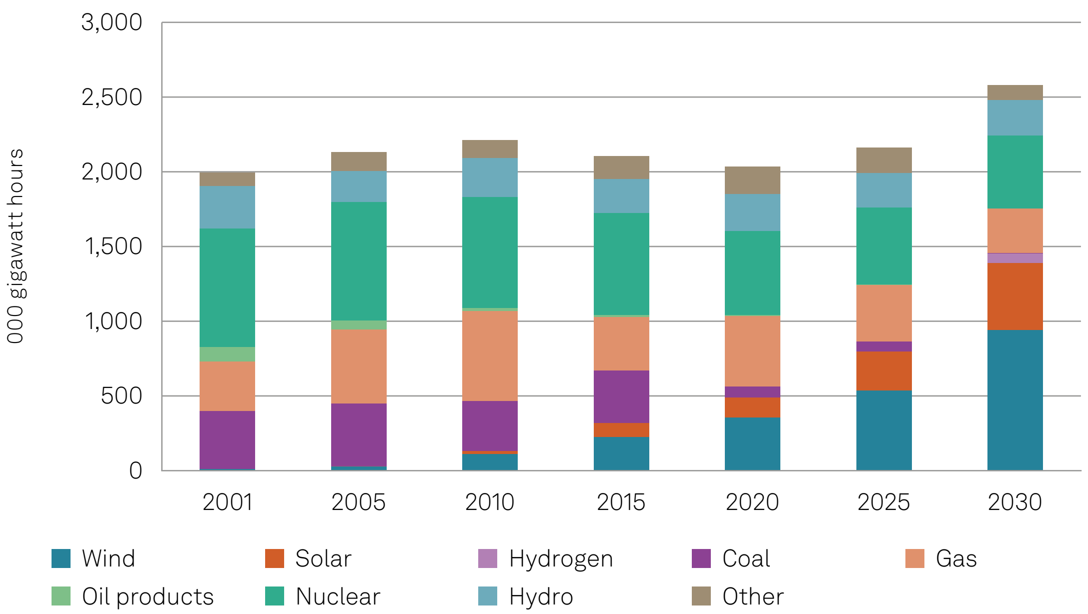
Published on Aug. 2, 2022

Key takeaways

- Renewables are forecast to increase to 60% of power generation in Europe by 2030, and possibly approach 40% in the U.S. and China, according to S&P Global Commodity Insights (Platts), but they will still account for only 18% of global energy demand.
- Continued policy support remains important to reduce credit risks from volatile and potentially declining long-term power prices as the share of zero- or low-marginal-cost plants increases.
- Security-of-supply considerations further support an accelerated renewables rollout, notably in Europe, while back-up facilities, including from power plants fueled by natural gas, may play an increasing role in the coming decades as the share of intermittent renewable power generation rises.

▶ **Renewable energy sources (solar, wind,** and hydro) account for the majority of annual investments in power generation. Yet they still represented only 13% of global primary energy consumption in 2020, according to S&P Global Commodity Insights (Platts). Climate policies, cost competitiveness and the strategies of power companies and investors will likely help this share increase to 18% by 2030 (two-thirds wind and solar, one-third hydro). This means that, by then, renewable energy could equate 60% of the primary energy previously sourced from oil, versus only about 25% a decade ago.

Chart 1: **Western Europe's power generation mix**



CCUS -- Carbon capture, usage, and storage. Source: S&P Global Commodity Insights - Global Integrated Energy Model
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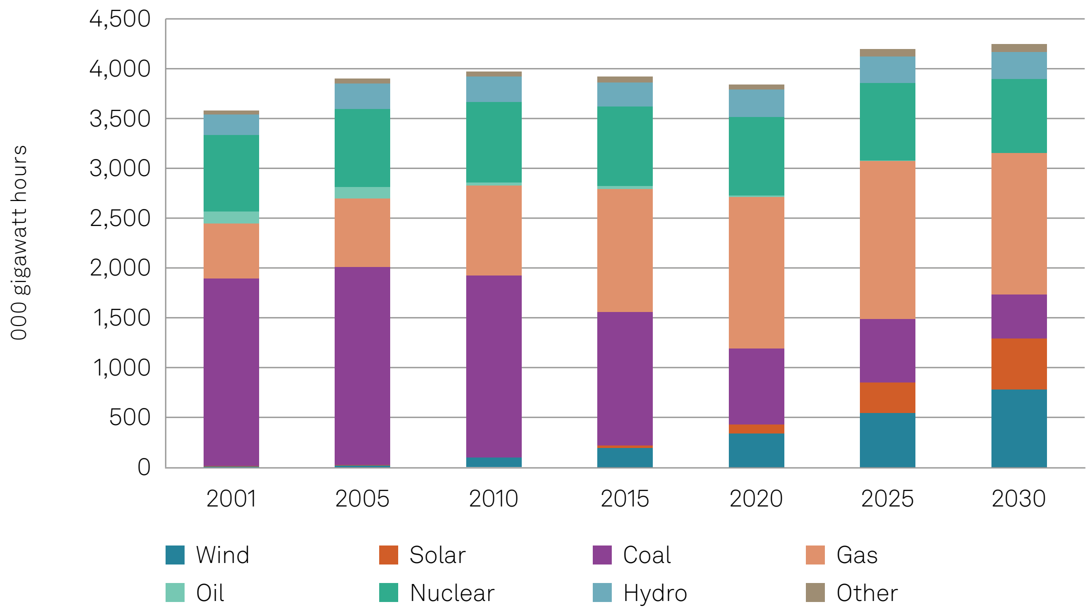
ENERGY TRANSITION

Chart 2: **U.S. power generation mix**



Source: S&P Global Commodity Insights - Global Integrated Energy Model
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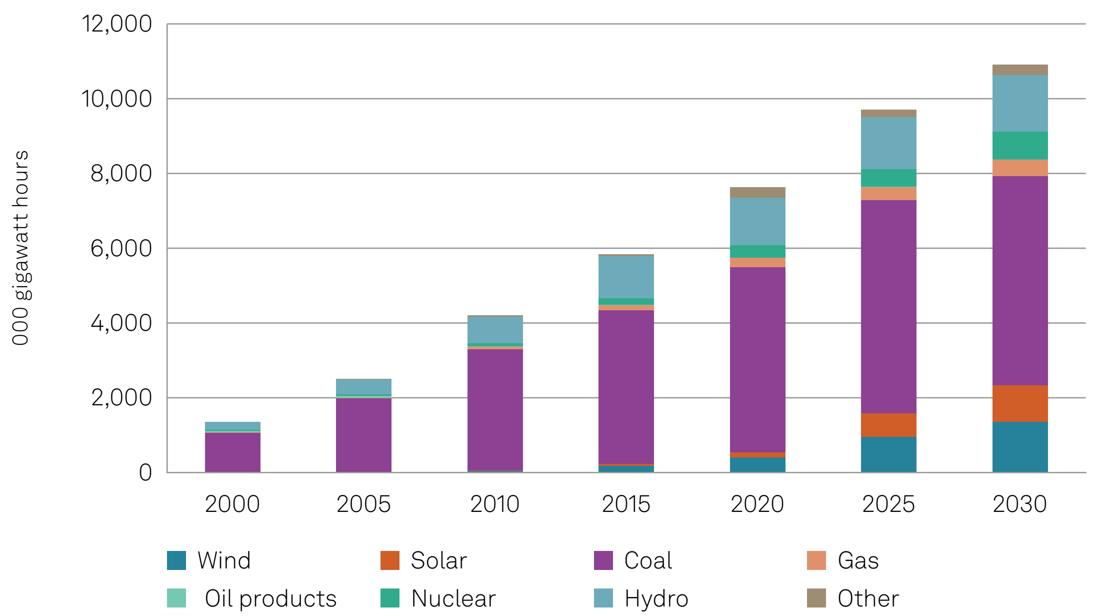
Chart 3: **China's power generation mix**



Source: S&P Global Commodity Insights - Global Integrated Energy Model
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The growth and importance of renewables in the power generation mix is however significantly higher. The S&P Global Commodity Insights (Platts) reference scenario puts the share of renewables in 2030 at more than 60% of the power mix in Western Europe, up from around 35% today, and 38% each in the U.S. (up from 23%) and China (up from 30%). As part of that increase, the projected expansion of solar and wind capacity is even more impressive, almost doubling this decade to 47% by 2030 in Europe (versus 25% in 2020), 32% in the U.S. (up from 12%), and 24% in China (up from 11%).

Capacity additions lag energy demand growth and a 2° pathway

Despite ongoing growth in renewables, gas- and coal-fired power generation continues to rise. This is due to steadily increasing power demand in developing markets (notably China and India), combined with global electrification trends, such as switching to electric vehicles and demand from a growing number of data centers including for bitcoin mining. What's more, in many markets there are still few incentives to build new renewables capacity to replace older fossil-fuel power plants that are fully depreciated, and the cost of carbon is not fully accounted for, in our view.

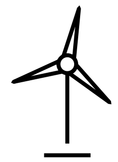
Accelerating the expansion of renewables generation, in line with limiting global warming to less than 2°C per year, would require significant additional momentum beyond market economics. The S&P Global Commodity Insights (Platts) 2° scenario would require renewable energy generation from solar, wind and hydro in 2050 to be almost double that expected in the reference case.

Supportive policies remain needed to foster growth

Renewable power generation has become competitive, especially in the current environment where fossil fuel prices are at record highs. However, we see that the solar and wind power industries still require wide-ranging policies that foster further growth, including investment in auxiliary technologies such as storage, grid upgrades and interconnections. For example, attaining permits for renewables projects is often cited as a major hurdle in the U.S. and Europe. To address this, and in view of the urgency resulting from the Russian gas crisis, Europe's recent REPowerEU plan now includes a proposal for "renewables go-to zones" and initiatives to limit legal recourse against new generation plants and grid buildups, as in Germany.

S&P Global Ratings believes policies to facilitate long-term price visibility for renewables investments are key to reducing credit risks and financing costs.

In the U.S., credit-supportive price visibility is often provided through power purchase agreements with utilities, which often result from renewable portfolio standards set by states. In Europe, a competitive auction process is mostly used for renewables, which has yielded a fixed price outcome or contracts for difference over 15 to 20 years and essentially acts as a swap of a long-term spot price into a fixed price, rather than as a subsidy. Even though the cost of renewables has decreased and is now competitive relative to that of other power generation sources, any unmitigated exposure to long-term power prices (and hourly capture rates) would unlikely be in line with investment-grade credit characteristics. This is because such exposure would make cash flows of renewable projects subject to significant uncertainty, similar to those of other merchant-type power projects. S&P Global Commodity Insights (Platts) expects power prices in Western Europe to decline sharply over the next decade, assuming gas prices start returning to normal levels. This is because of the rising share of zero- or low-marginal-cost plants in the generation mix.



The solar and wind power industries still require wide-ranging policies that foster further growth, including investment in auxiliary technologies such as storage, grid upgrades and interconnections.

Key renewables objectives for Europe, the U.S., and China by 2030

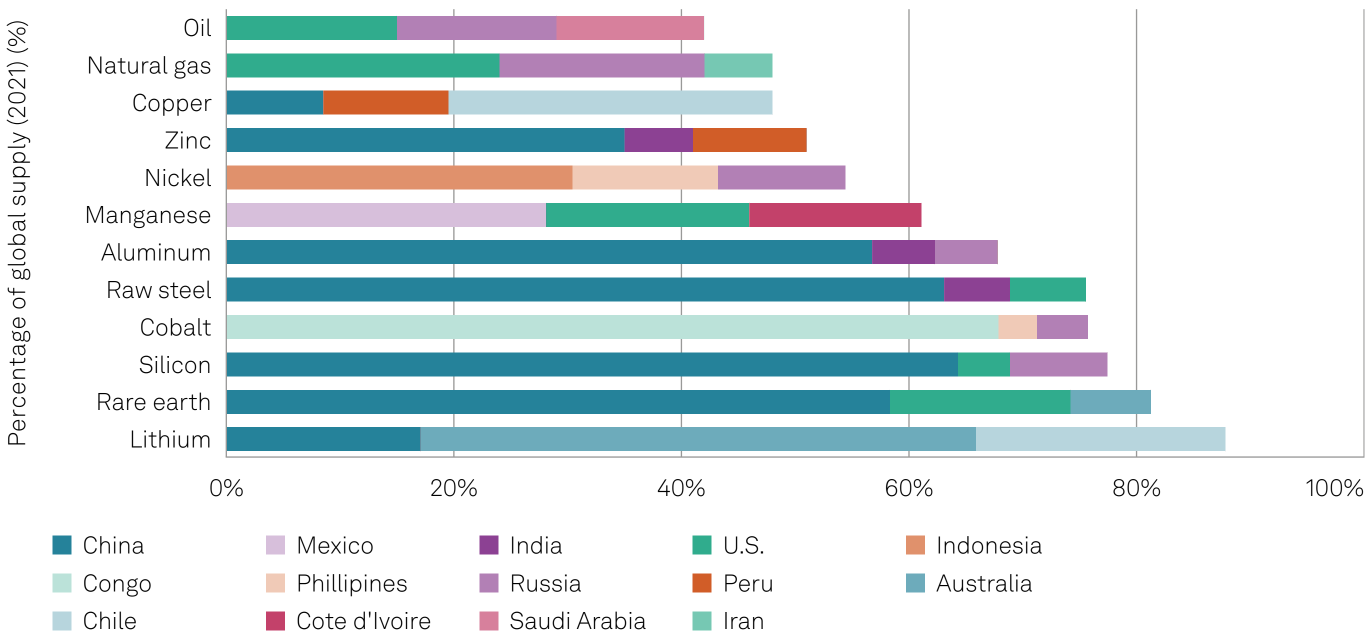
Russia's invasion of Ukraine has added new impetus for Europe to double down on its energy transition targets. The goal of reducing dependence on Russian gas and promoting energy independence now complements the region's push toward net zero. The REPowerEU strategy has raised the target for the share of renewables (including hydro) to meet energy demand to 45%, compared with 40% in the existing Fit for 55 plan. To this end, REPowerEU aims to have 1,236 gigawatts (GW) of wind and solar generation capacity online by 2030, up from about 350 GW of installed capacity today.

In the U.S., the increasing bifurcation of political views is hampering support for climate-oriented policies. A recent U.S. Supreme Court decision curtailed – though did not end – the Environmental Protection Agency's ability to regulate power sector greenhouse gas emissions under the Clean Air Act. From the standpoint of renewable energy growth, the Inflation Reduction Act of 2022 opens the door to clean energy investments across the next decade, including new and expanded clean energy tax credits. This notwithstanding, renewables growth in the U.S. should remain underpinned by cost competitiveness and decarbonization strategies of many utility companies. Moreover, state legislation, such as renewable portfolio standards, is not affected by the court's decision. Based on the S&P Global Commodity Insights (Platts) reference case, we foresee installed wind and solar capacity reaching 510 GW by 2030, up from 225 GW at the end of 2021.

We expect that China will deliver on or surpass the target in its recently announced 14th five-year plan. The plan includes a target of renewables (excluding hydro) to cover 18% of primary energy consumption by 2025. This requires 1,100 GW of installed wind and solar power capacity, almost double the currently installed capacity of about 640 GW (330 GW from wind and 307 GW solar photovoltaic) at year-end 2021, and is already close to the official target of 1,200 GW by 2030. Given that China has been adding 100 GW of renewables capacity per year, its 2030 target is therefore well within reach and likely to be exceeded. The power market is mainly led by state-owned enterprises with limited funding issues.

Chart 4: **Top three mining countries**

Total mineral and material production compared to fossil fuels



Source: International Energy Agency, U.S. Geological Survey.

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Reliance on China for equipment and raw materials poses risks

Recent supply chain issues have hampered renewables growth, but we believe this should be more manageable in the medium term. Despite accounting for about half of global annual installations, China dominates the global solar supply chain. High dependence on China for raw materials key to the energy transition has also been underscored by the International Energy Agency (see chart 4).

There is, however, no one-to-one comparison with dependence on oil- or gas-producing countries, since once renewable power plants are installed, the dependence on China decreases significantly because wind and solar are indigenous fuel sources. Still, U.S. and European governments are already considering alternative suppliers outside China as well as the onshoring of key strategic investments, such as batteries and related lithium mining, semiconductors and photovoltaic solar panels.

As more fossil fuel plants close due to age or environmental mandates, and the share of renewables in the power mix expands, there will be a need for flexible dispatchable power that addresses the intermittent nature of renewables. Low-carbon solutions, including batteries, can address short-term supply needs but are unlikely to cope with major seasonal fluctuations in energy demand.

However, these solutions still come with a high price tag, which needs to be added to the cost of renewable generation to arrive at an all-in cost of providing firm power that is available at all times. The more likely interim solution, therefore, may be to steadily increase the contribution from renewables, while adding gas-fired peaking plants or providing a capacity payment mechanism to existing gas- or coal-fired plants to allow them to act as back-up capacity and be available during periods of low power output from renewables.

Likewise, interconnections will play a key role in reducing intermittency risks, since they link markets with different resource mixes. For example, in Europe there is significant renewables generation in Denmark (74% of total generation in 2021), but grid stability is supported by a comprehensive interconnection network across the region, which is now being expanded to the U.K. The development of such networks requires, however, long commissioning time frames.

Affordable and reliable power is likely to be an increasing area of focus for all countries.

- The European Commission and European Parliament have just approved certain (peak) natural gas power plants to be designated as green sustainable investments.
- In the U.S., California – where renewables now account for 33% of power generation – could delay the closure of the Diablo Canyon nuclear plant after the state faced rolling blackouts and increased fluctuations in renewable output in recent years. Other states that have a lower proportion of renewables are also running into issues. The mid-continent region operator, MISO, recently issued a warning about blackouts for Michigan and there have been some deferrals of coal retirements.
- China is supporting coal supply in 2022 to ensure power stability but factoring into the equation an affordable energy transition. Last year, the country's commercial and industrial sectors experienced power shortages. China is using a combination of tariffs and measures such as "dual-control" to fuel growth of renewables while still supporting firm power from coal (see "China will establish dual control system for cutting emissions, carbon intensity: Xi," Jan. 27, 2022). ■

This report is part four in a five-part series providing insights on developments in the energy transition. **Click here to see the full series.**

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The future of copper: Will the looming supply gap short-circuit the energy transition?

Technologies critical to the energy transition such as electric vehicles, charging infrastructure, solar photovoltaics, wind, and batteries all require much more copper than conventional counterparts. Research from S&P Global's Economics & Country Risk, Commodity Insights, and Mobility teams shows that this growing appetite for copper could be an obstacle for energy transition and climate goals. Demand for copper will double by 2035, opening a supply gap that poses serious challenges to reaching net zero emissions by 2050.

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Key takeaways

- Copper — the "metal of electrification" — is essential to all energy transition plans. But the potential supply-demand gap is expected to be very large as the transition proceeds. Substitution and recycling will not be enough to meet the demands of EVs, power infrastructure and renewable generation. Unless massive new supply comes online in a timely way, the goal of net zero emissions by 2050 will be short-circuited and remain out of reach.
- Copper demand is projected to grow from 25 million metric tons (MMt) today to about 50 MMt by 2035, a record-high level that will be sustained and continue to grow to 53 MMt by 2050. Power and automotive applications will have to be deployed at scale by 2035 in order to meet the 2050 net zero targets.[1]
- The chronic gap between worldwide copper supply and demand projected to begin in the middle of this decade will have serious consequences across the global economy and will affect the timing of net zero emissions by 2050.
- The shortfall will reach as high as 9.9 MMt in 2035 in what we call the Rocky Road Scenario, which is based on a continuation of current trends in capacity utilization of mines and recycling of recovered copper. This would mean a 20% shortfall from the supply level required for the target of net zero emissions by 2050.
- The gap arises even under assumptions of aggressive capacity utilization rates and all-time-high recycling rates in a High Ambition Scenario. Even with these aggressive assumptions, refined copper demand will outpace supply in the forecast period up to 2035.
- In the 21st century, copper scarcity may emerge as a key destabilizing threat to international security. Projected annual shortfalls will place unprecedented strain on supply chains. The challenges this poses are reminiscent of the 20th-century scramble for oil but may be accentuated by an even higher geographic concentration for copper resources and the downstream industry to refine it into products.
- In the U.S., the nexus between a politicized regulatory process and the ubiquity of litigation makes it unlikely that efforts to expand copper output would yield significant increases in domestic supply within the decade. The prospects for any expansions are higher on state and private lands.
- Under the Rocky Road Scenario, the U.S. will have to import 67% — that is, two-thirds — of its refined copper demand by 2035. Even in the High Ambition Scenario, the U.S. will still need to import 57% of the refined copper during the years of highest energy transition–related copper demand.
- The complexity of permitting mines in the U.S. is reinforced by the long lead times also required elsewhere around the world. Multidimensional challenges make the development of mines a generational endeavor, spanning decades and requiring hundreds of billions of dollars. Projects under development today would likely not be sufficient to offset the projected shortfalls in copper supply, even if their permitting and construction were accelerated.

[1] A metric ton is a metric unit of mass equal to 1,000 kilograms. It is also referred to as a tonne. It is equivalent to approximately 2,204.6 pounds; 1.102 short tons; and 0.984 long tons.

A number of authorities have expressed alarm as to whether there will be enough minerals to meet the requirements for the goal of net zero emissions by 2050. These include, among others, the United States government, the European Union, the International Monetary Fund, the World Bank and the International Energy Agency (IEA). The last, the IEA, has summarized the challenge as being driven by the move from "a fuel-intensive to a mineral-intensive energy system."

This study seeks to respond to that concern by focusing on copper, which can be described as the "metal of electrification." Many nations, including the U.S. and the EU, have set net zero emissions by 2050 as their climate goal. Accordingly, this target was chosen as the basis for the study.

The study seeks to quantify the amount of additional copper that will be required by increased electrification and the energy transition — most specifically, the rapid move to electric vehicles (EVs) and renewable electricity and the need for increased electricity infrastructure. It concludes that copper demand will double by 2035 and continue to grow thereafter. On the supply side, it finds how challenging that will be, whether on the basis of current trends or with an unprecedented acceleration of supply from mining and recycling.

The study makes no policy recommendations. Rather, it seeks to respond to the urgent concern of the authorities above and others by quantifying the copper requirements of net zero emissions by 2050 and benchmarking them against the supply response. We hope that this study will be a contribution to the continuing dialog about achieving net zero emissions by 2050.

The Key Findings and Executive Summary of this report are featured here in the S&P Global Sustainability Quarterly.

For more information and to access the full report, please **click here**.

S&P Global is exclusively responsible for this report and all of the analysis and content contained herein. It represents the collaboration of S&P Global's Commodity Insights, Economics & Country Risk unit within Market Intelligence, and Mobility divisions. The analysis and metrics developed during the course of this research represent the independent analysis and views of S&P Global and are intended to contribute to the dialogue on the copper required to meet the energy transition requirements under net zero emissions by 2050.

Executive Summary

▶ This report examines the looming mismatch, on a global basis, between available copper supply and future copper demand resulting from the energy transition. It highlights the increasing uncertainty surrounding whether burgeoning global climate change ambitions can be satisfied with existing and potential sources. Unless new supply for "the metal of electrification" comes online in a timely way, net zero emissions by 2050 will be short-circuited and remain out of reach.

Plentiful access to certain "critical minerals" is crucial to delivering on the widespread commitments to eliminate global net carbon dioxide (CO_2) emissions by 2050 (although major emitters like China and India are, respectively, targeting 2060 and 2070).[2] Paramount to achieving these goals is electrifying the global vehicle fleet and aggressively switching to renewable energies for power generation, which are two of the primary prongs of the energy transition.[3] While a variety of metals and rare earth elements have received a great deal of attention by governments, media, think-tanks and universities, one of the most underappreciated critical minerals is also one of the most familiar and most fundamental — copper. Deeper electrification requires wires, and wires are primarily made from copper. Moreover, copper ore deposits often contain other critical minerals wherein those mining operations yield significant by-product production of other metals such as cobalt, molybdenum and nickel.

The analysis in this report is built from a detailed bottom-up approach, technology by technology, and compares projected copper demand resulting from the energy transition against projected copper supply. It represents the collaborative work of groups within S&P Global, including the Economics & Country Risk team within Market Intelligence, Commodity Insights, and Mobility.

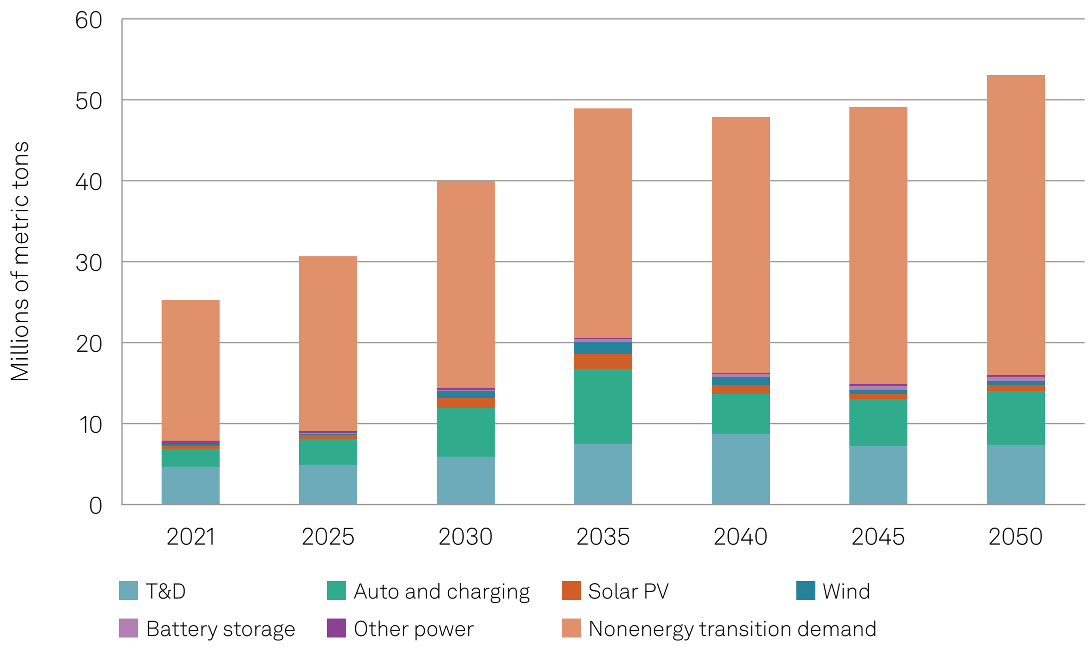
On the demand side, the analysis works bottom up — that is, in a granular way — technology by technology, from assumed implementation of the announced U.S. and EU goals of net zero emissions by 2050. These policies are the starting point for the analysis, not recommendations. On the supply side, the study offers two views of the future: (1) the High Ambition Scenario, which is based on highly optimistic assumptions about advances in recycling and capacity utilization of mines and refineries; and (2) the Rocky Road Scenario, which is based on a continuation of recent recycling and capacity utilization rates, which are lower.

The key point is this: technologies critical to the energy transition such as EVs, charging infrastructure, solar photovoltaics (PV), wind and batteries all require much more copper than conventional fossil-based counterparts. The rapid, large-scale deployment of these technologies globally, and EV fleets particularly, will generate a huge surge in copper demand. Major investments in the power grid to support electrification will further amplify the trend. Meanwhile, copper continues to be a critical material for many other sectors of the economy not directly related to the energy transition but fundamental to overall economic growth and development, and from which copper consumption is projected to grow continuously. The result of the energy transition growth on top of traditional growth will be an overall more than doubling of copper demand by 2050.

2 "Critical minerals" is a term often used in the United States. The list of 50 items (in 2022) produced by the U.S. Geological Survey uses criteria defined in the (U.S.) Energy Act of 2020. Most of these are widely used across the industry and may or may not be used in carbon emissions-reducing applications. The European Commission similarly produces a "critical raw materials" list; and China published a list of "strategic minerals" under its National Mineral Resources Planning, 2016-2020.

3 Assumptions for electrifying the global fleet include the increased penetration of fuel-cell electric vehicles, powered by hydrogen.

Global refined copper usage



Note: Based on S&P Global's Multitech Mitigation scenario; US values are adjusted to align with Biden administration's net-zero ambitions. T&D = transmission and distribution; PV = photovoltaics; other power includes conventional generation (coal, gas, oil, and nuclear), geothermal, biomass, waste, concentrated solar power, and tidal.
Source: S&P Global analysis

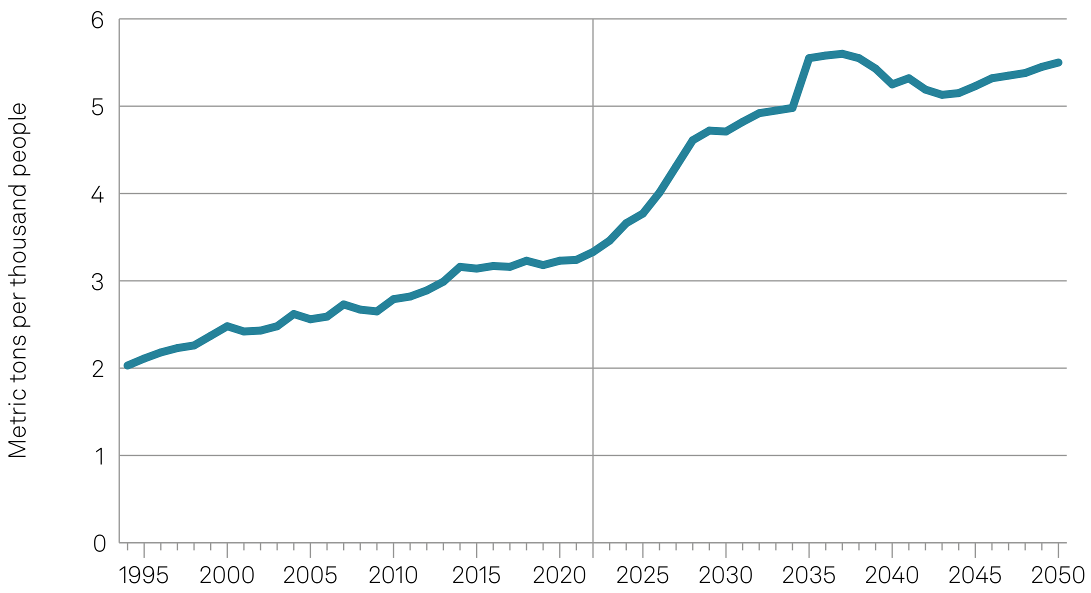
This study finds that copper demand from the energy transition will accelerate steeply through 2035. Crucially, this dramatic escalation occurs well before 2050 while traditional growth continues to ramp up. The conclusion: achieving the stated climate ambitions will require a rapid and massive ramp-up of copper supply far greater than is visible in any private or public plan.

This energy transition demand growth will be particularly pronounced in the U.S., China and Europe. India will also exhibit strong copper demand growth, albeit more from traditional copper applications. The High Ambition Scenario assumes that ramped-up demand growth will coincide with record-high rates of copper mine capacity utilization and recycling, but even these aggregated improvements will be insufficient to close the gap. In the Rocky Road Scenario, the shortfall will be much greater, and sooner.

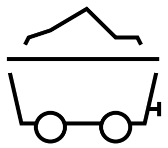
The initial increase in demand over the coming decade will be particularly challenging. Global refined copper demand is projected to almost double from just over 25 MMt in 2021 to nearly 49 MMt in 2035, with energy transition technologies accounting for about half of the growth in demand. The world has never produced anywhere close to this much copper in such a short time frame.

Demand from nonenergy transition end markets — such as building construction, appliances, electrical equipment, brass hardware and cell phones, as well as expanding applications in communications, data processing and storage — is also expected to continue to grow, rising at a compounded annual rate of 2.4% between 2020 and 2050. Altogether, total refined copper demand is expected to reach approximately 53 MMt in 2050. It is important to note that copper demand would see significant increases over the

Global refined copper consumption per capita



Source: International Copper Study Group (ICSG), S&P Global



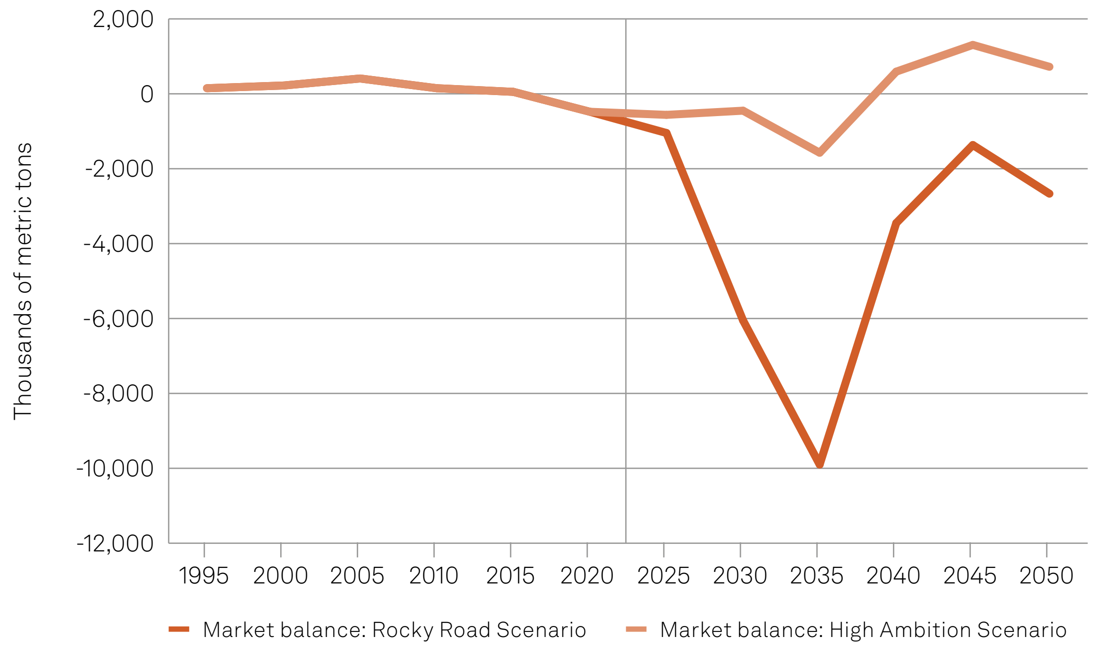
China holds a preeminent position in copper smelting (47%), refining (42%) and usage (54%), in addition to its sizable position in production, making it the epicenter of world copper.

projection period even in a world that did not fully transition to net zero. Copper demand from energy transition end markets is expected to reach a maximum of almost 21 MMt in 2035. This surge in demand to meet net zero emissions by 2050 requires a near doubling of today's global copper supply by 2035, an expansion that current exploration trends or projects in the feasibility stage of development are incapable of meeting.

Per capita consumption of copper has been rising steadily since the early 1990s. Per capita consumption growth will accelerate markedly between 2024 and 2035 as investments to meet net zero emissions by 2050 targets are made and developing countries continue to industrialize. After the middle of the next decade, copper consumption per capita plateaus as EV sales begin to slow once fleets are mostly electrified. In a world moving to net zero, new copper supplies will be necessary to maintain this elevated level of consumption.

This study finds that copper supply shortfalls begin in 2025 and last through most of the following decade. In the High Ambition Scenario, surpluses will likely emerge in the 2040s as energy transition copper demand slows and secondary production (the refining of recycled copper) sees an upswing. If capacity utilization and recycling rates do not improve and instead reflect their average rates over the past decade — as in the Rocky Road Scenario — then these surpluses would not arise and a much steeper gap between supply and demand would persist through 2050. Unless the considerable gap between demand requirements and supply realities is closed, especially between 2025 and 2035, the 2050 target for net zero will be pushed further into the future.

Global copper market balance



Source: ICSG, S&P Global

The challenge will be compounded by increasingly complex global geopolitical, trade, and country-level risk environments. There are several dynamics that will have a particular bearing on copper access. China holds a preeminent position in copper smelting (47%), refining (42%) and usage (54%), in addition to its sizable position in production, making it the epicenter of world copper. Continued trade tensions and other forms of competition between the U.S. and China could affect the copper market going forward. Supply chain resilience has emerged as a strategic imperative, particularly after the COVID-19 pandemic and the war in Ukraine. The study finds that by 2035 the U.S. will be importing between 57% and 67% — that is, up to two-thirds — of its copper needs. An intensifying competition for critical metals is very likely to have geopolitical implications.

In a period of high demand, prices will rise, which is a stimulus to investment. While price is a significant incentive, there are other considerations that also affect the pace of investment. These include the absence of actual development opportunities, as well as environmental issues, social license to operate, relationships with local communities, and locational accessibility.

The resulting challenge for all actors involved in the energy transition will be to manage sometimes competing and often contradictory priorities. To achieve net zero emissions by 2050 will likely require major innovations in technology and approaches to policies, including ones that encourage long-term investment, because there is no way to forestall the projected shortages in copper without taking steps to increase supply. Three priority areas stand out for consideration and further refinement given the findings of this study:

THE FUTURE OF COPPER

- **Policy:** Regulatory and fiscal regimes need to be stable and predictable to encourage investment and facilitate construction of new mines, processing facilities and recycling plants. Mines are generational endeavors requiring billions, even tens of billions, of dollars with development timelines that span decades. Clear policy objectives that connect critical minerals production with clean energy end-use goals would provide investment stability and assure long-term political acceptance and social license — important steps for reducing the delay in developing new copper resources for the market.

- **Technology:** Innovation that enables cleaner, more efficient and lower-cost extraction and refining of copper could help increase supply directly. If such innovation addressed environmental and social concerns of a growing portion of investors, then it would also attract more capital into the industry and increase supply indirectly.

- **Interdependencies:** The energy transition will require not only more copper but also other critical minerals, many of which are only produced as co-products or by-products of copper processing (smelting and refining). Some of these are already identified under nascent government initiatives — particularly in the U.S. and the EU — while others are not. Understanding these wider interdependencies will be important to ensure that the path forward is not blocked by similar issues emerging for other critical minerals required for increased electrification. ■

To continue reading and access the full report, please **click here.**

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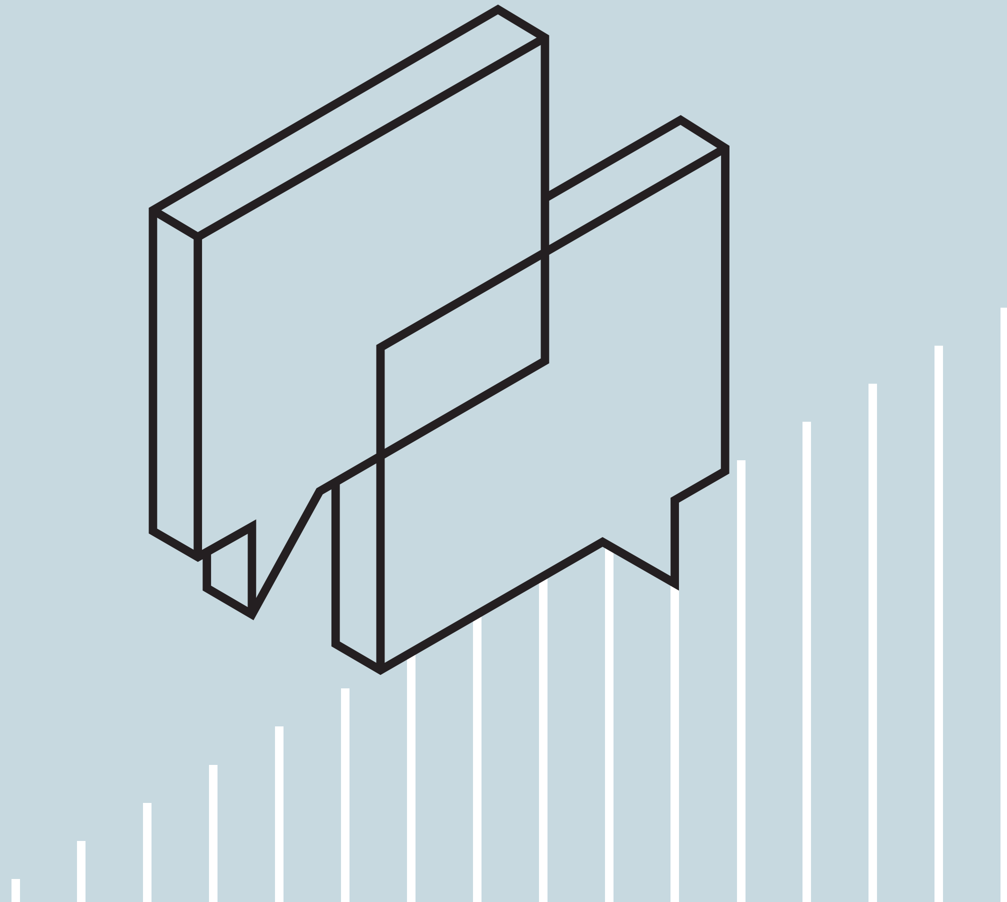

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