Hot Spots: Subnational Regions Outside The U.S. Face Rising Physical Climate Risks

Nov. 12, 2024

Data and scenario analysis show that almost all subnational regions outside the U.S. could become hotter and drier by 2050, and some may see more frequent extreme flood events.

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

This report does not constitute a rating action.

Authors

Sustainability Research

Paul Munday
London
paul.munday
@spglobal.com

Sovereigns and International Public Finance Credit Ratings

Bhavini Patel
Toronto
bhavini.patel
@spglobal.com

Alejandro Rodriguez Anglada
Madrid
alejandro.rodriguez.anglada
@spglobal.com

Contributors

Zoe Parker
London

Felix Ejgel
London

Lisa Schineller
New York

See complete contact list at end of article.

S&P Global
Ratings

In previous research "Lost GDP: Potential Impacts Of Physical Climate Risks," Nov. 27, 2023, S&P Global Ratings found that up to 4.4% of the world's GDP could be lost each year by 2050 if global warming doesn't stay well below 2 degrees Celsius (2 C). We've also analyzed the exposure of U.S. local governments to physical climate risks (see "Navigating Uncertainty: U.S. Governments And Physical Climate Risks," Apr. 23, 2024).

This research examines the potential exposure of subnational regions outside the U.S., that is, those managed by local and regional governments (LRGs), to physical climate risks. Its aim is to provide insights on how worsening climate hazards might influence key credit factors for the governments of such regions and how they are preparing for and managing these risks.

We use the same data as for the Lost GDP research--S&P Global Sustainable1's Country and Subnational Climate Physical Risk Dataset (hereafter S1 dataset)--focusing on 95 non-U.S. LRGs we rate. We analyzed exposure data for nine climate hazards over various timescales and greenhouse gas emissions scenarios through the Shared Socioeconomic Pathways (SSPs). Limitations of the dataset are described in the appendix.

Consistent with our criteria, our credit ratings incorporate the adverse physical effects of climate change--that are sufficiently visible and material--along with all other factors material to our assessment of creditworthiness.

We do this when we believe such impacts could materially influence the creditworthiness of a rated entity or issue and we have sufficient visibility on how they will evolve or manifest.

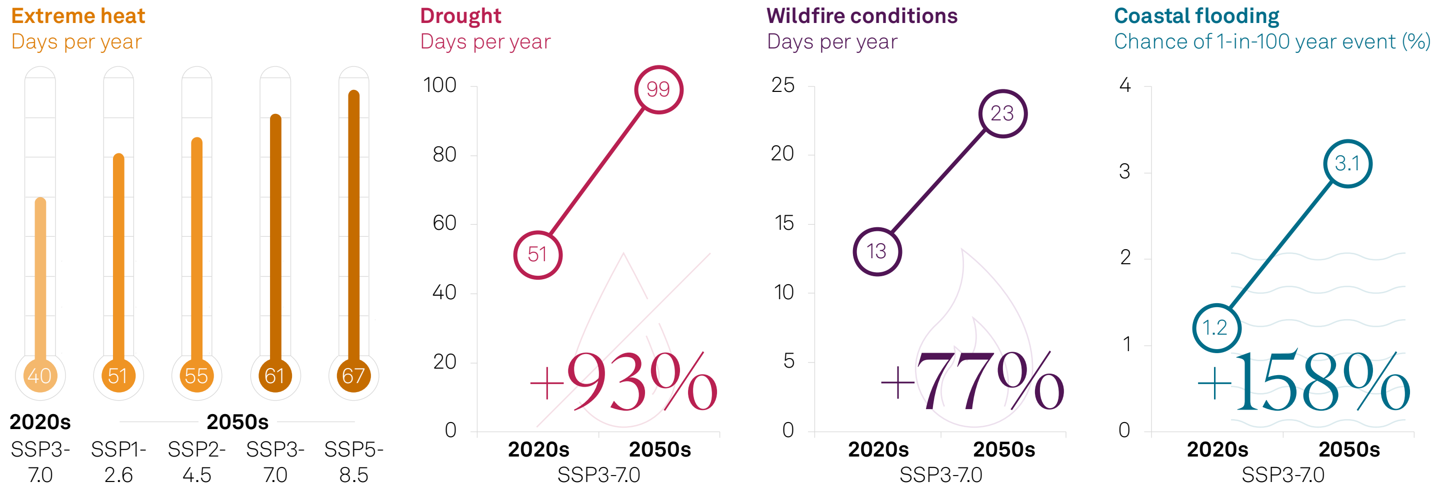
However, the findings of this research are currently not part of our base case for Local and Regional Government ratings, given the uncertainties inherent in climate projections.

Key Findings

- **Almost all non-U.S. subnational regions face rising exposure to climate hazards but the magnitude differs by hazard and region**. Almost all are projected to become hotter and drier by 2050, and some could see more frequent extreme flooding. Without adaptation investments, this could increase credit risks for some governments.
- **Compound climate hazards (such as droughts followed by floods after heavy rainfall) are more likely to occur in many subnational regions by midcentury.** Compound events may exacerbate economic impacts and increase both the costs and urgency to implement adaptation and resilience measures.
- **Adverse impacts on LRGs' credit quality will likely be uneven.** Transmission channels to creditworthiness also depend on central governments' ability and willingness to help shoulder the costs of adaptation and resilience measures.
- **Climate data can help inform our analysis, but this alone won't necessarily lead to rating actions.** Such data may provide a starting point to help inform discussions with management and our forward-looking credit opinions.

By the numbers: Climate hazards will likely worsen in rated non-U.S. subnational regions

Changes by the 2050s under different Shared Socioeconomic Pathways (SSPs)



Sources: S&P Global Ratings, S&P Global Sustainable1.

Exposure To Physical Climate Risks Could Have Economic And Financial Consequences

Direct damage from climate hazards has more than doubled in real terms since the early 2000s, reaching $275 billion in 2022, as reported by the Network For Greening The Financial System

Extreme weather events and chronic physical climate risks are worsening across the globe; 2011-2020 was the warmest decade on record after successive temperature increases since the 1990s, according to a World Meteorological Organization report. Economic losses from worsening climate hazards are also rising. Direct damage from climate hazards has more than doubled in real terms since the early 2000s, reaching $275 billion in 2022, as reported by the Network For Greening The Financial System. A report by the U.N. Office for Disaster Risk Reduction states that, if mitigation of greenhouse gas emissions is not stepped up, there could be 40% more disasters globally by 2030 than in 2015, with 250 events per year.

The impacts on economic growth from climate hazards will likely be heterogeneous and we project they will rise, absent adaptation. Up to 4.4% of the world's GDP could be lost annually without adaptation measures, disproportionally affecting developing economies (see "Lost GDP: Potential Impacts Of Physical Climate Risks," published Nov. 27, 2023). The rising likelihood of compound events--climate hazards occurring at the same time or consecutively--may exacerbate ongoing economic weakness, particularly in developing economies. Delayed adaptation or no adaptation may increase the costs and the amount of change required to adapt to climate change, according to the European Environment Agency.

All governments, including in the U.S., may need to spend more to address risks posed by worsening climate hazards. A report by the U.N. Environment Program (UNEP) estimates the cost of adaptation measures for developing countries at $215 billion-$387 billion per year--or 0.6%-1.0% of GDP--for this decade alone. However, it could be challenging for developing countries to attract investors, given the perception of greater credit risk (see “Investments In Climate Adaptation Needs Have High Returns On Growth,” Jan. 10, 2024). Blended finance (pooling public-sector funds with private-sector capital) is increasingly being seen as a way to scale up much needed climate investments (see “5 Big Climate Week NYC Ideas We Expect To See At COP16 And COP29,” Oct. 11, 2024).

Data And Approach: Assessing Non-U.S. Subnational Regions' Physical Risk Exposure

Our analysis and research for this article leverage the S1 dataset on the exposure of national and subnational issuers to nine climate hazards: extreme heat, extreme cold, wildfire, drought, water stress, coastal flooding (sea-level rise), fluvial flooding (severe river flooding), pluvial flooding (severe rainfall), and storms (tropical cyclones, hurricanes, and typhoons).

The S1 dataset covers the period from the current decade through to midcentury for 201 countries and 2,098 subnational regions, under four SSPs (see next page). Of those 2,098 subnational regions outside the U.S., we analyzed the 95 entities we rate (see Appendix). In addition to the S1 dataset, we use information on GDP and population to better understand the potential sensitivity of those subnational regions to different climate hazards.

This two-pronged approach, in our view, provides a reasonable estimate of climate exposures that could affect LRGs' revenue. We use thresholds (see Table A1 in the Appendix) to calculate the percent of GDP and population exposed to each climate hazard, and thereby define areas of high physical risk exposure.

The S1 dataset helps identify:

- Climate hazards that could pose material challenges to each subnational region in each decade;
- Subnational regions that could face compound physical climate risks, that is, from climate hazards occurring at the same time or consecutively; and
- Subnational regions that could face the greatest exposure to physical climate risks by 2050.

Scenarios allow comparison of multiple potential exposures

To better illustrate the potential credit impacts of physical climate risks, the S1 dataset applies four SSPs (see below). Given the lock-in effect of historical greenhouse gas emissions, many physical risks of climate change will materialize regardless of today's policy choices. This is particularly the case for timepoints before the midcentury (see the Intergovernmental Panel on Climate Change [IPCC]'s Sixth Assessment Report: Summary For Policymakers). Countries' current commitments, if met, align with a global temperature increase of 2.4 C to 2.6 C by 2100, according to UNEP. This is similar to SSP2-4.5.

Using a range of scenarios helps us understand the likely transmission channels of credit risk and the potential impact on credit quality (see "Scenarios Show Potential Ways Climate Change Affects Creditworthiness," July 25, 2024). This may enhance our forward-looking credit analysis of LRGs, and their regions' potential future exposures, against the LRGs' resilience and risk management strategies, while also considering the potential costs and benefits they identified.

Shared Socioeconomic Pathways Defined

The IPCC's SSPs are a set of scenarios for projected greenhouse gas emissions and temperature changes. They incorporate broad changes in socioeconomic systems, including population growth, economic growth, resource availability, and technological developments.

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

In this research, we consider subnational regions' exposures to climate hazards primarily using SSP3-7.0 through to 2050 given this lock-in effect and inherent challenges and uncertainties associated with long-term projections. Because of these uncertainties, we applied the other SSPs to describe a broader range of possible outcomes, where appropriate.

How the metrics in our analysis capture changes in climate hazards

Various metrics capture change in climate hazards over time through values by decade (see table 1).

- For the **extreme heat** climate hazard, the S1 dataset defines extreme heat conditions as temperatures exceeding the local daily maximum temperature for 5% of all days in 1950-1999. We assume in our analysis that each location is currently adapted to its respective historical frequencies of extreme heat events, and that any future increase in temperature exceeds what would be expected due to natural variability.
- Flood-related hazards--such as **coastal, fluvial,** and **pluvial flooding**--are expressed as the annual frequency of days in excess of the historical 100-year flood level. This metric uses the annual probability of flooding, based on the decadal average.
- The **water stress** metric is based on the projected ratio of demand to basin-specific water supply (from both groundwater and surface water sources), expressed in absolute terms. This metric is reported using a 0-1.0 range, and it describes the state of water availability (calculated based on a decadal average) for the local water basin. A value of 0.4 or higher is defined as high water stress (see table A1 in the appendix).
- Other climate hazards--such as **wildfires** and **droughts**--are based on indices that express, respectively, general fire intensity potential and climatic conditions favorable to drought. For wildfire, the index is further enhanced by incorporating land cover containing or adjacent to burnable vegetation, urban areas, or bodies of water. Both climate hazards are expressed as the absolute frequencies of extreme conditions on an annual basis.

The metrics in our analysis can help explain potential changes in exposure to these climate hazards that subnational regions outside the U.S face. However, other variables can contribute to increased or decreased vulnerability. These include demographics, economic situation, and fiscal vulnerabilities to specific hazards; prior adaptation measures; how quickly a climate hazard may escalate in a given time frame and scenario; and whether there is potential for multiple climate hazards.

Table 1

Analysis metrics, definitions, and spatial resolution for the nine climate hazards

Climate hazard	Analysis metric	Metric definition	Spatial resolution
Extreme heat	Projected maximum temperature is warmer than the 95th percentile local baseline daily maximum temperature	Annual percentage of days with maximum temperature warmer than the 95th percentile local baseline daily maximum temperature	~25x25km
Extreme cold	Projected minimum temperature is colder than the fifth percentile local baseline daily maximum temperature	Annual percentage of days with minimum temperature colder than the 5th percentile local baseline daily minimum temperature	~25x25km
Coastal flooding (sea-level rise)	Frequency of 100-year coastal flood	Projected frequency of the historical baseline 100-year coastal flood depth	90x90 meters

Climate hazard	Analysis metric	Metric definition	Spatial resolution
Fluvial (river) flooding	Frequency of 100-year fluvial flood	Projected frequency and extent of the historical baseline 100-year flood depth	~1x1km
Pluvial (rainfall) flooding	Frequency of 100-year rainfall event	Projected frequency of the historical baseline 100-year daily precipitation rate	~25x25km
Tropical cyclones	Frequency of category 3 and higher storms	Projected annual frequency of category 3 and higher tropical cyclones	~25x25km
Wildfires	Fire Weather Index (FWI)	Projected frequency of days classified as high, very high or extreme based on the FWI, adjusted for land cover/presence of burnable vegetation	~25x25km
Water stress	Water Stress Index	Projected future ratio of water withdrawals to total renewable water supply in a given area	River basin
Drought	Standardized Precipitation-Evapotranspiration Index (SPEI)	Projected frequency of months classified as showing moderate drought, severe drought, or extreme drought based on the SPEI	~25x25km

km--kilometer. Source: S&P Global Sustainable1.

Climate Hazards Will Be More Prevalent By 2050

The S1 dataset shows that, for eight of the nine hazards (other than extreme cold waves), their projected frequency increases or remains static through the 2050s under a slow transition scenario (SSP3-7.0). The extent of climate hazard exposures is heterogenous and can vary significantly across, and within, regions.

However, we observe a number of broad trends among the 95 rated non-U.S. subnational regions covered in this research:

- **Extreme heat is expected to become more prevalent in nearly every subnational region outside the U.S.** The median annual number of days when temperatures exceed the historical 95th percentile daily maximum temperature is projected under SSP3-7.0 to rise from 40 in the 2020s to 61 by the 2050s. An increase--to 55 days per year--is also projected under a moderate transition scenario (SSP2-4.5). Under a limited mitigation scenario (SSP5-8.5), the projected annual number of days of extreme heat rises to 67 per year by the 2050s.
- **Wildfire risk remains largely linked to geography and is projected to rise under all scenarios, even the low-emissions scenario (SSP1-2.6), albeit to a lesser extent than certain other climate hazards.** Population growth and economic development that expand the wildland-urban interface area and density may contribute to the increase of this risk. Under a slow transition (SSP3-7.0), the median annual likelihood of conditions conducive to wildfires increases from about 13 days in the 2020s to slightly more than 23 days by the 2050s.
- **Exposure to drought conditions is projected to rise globally**. The median frequency of months experiencing at least moderate drought conditions rises from 13% in the 2020s to 29% by the 2050s.
- **Exposure to extreme flooding events is shown to increase gradually through the 2050s under all emissions scenarios.** Rising temperatures are expected to contribute to increasing weather variability. These effects are particularly acute for subnational regions exposed to rising sea levels.

Economic losses could rise as warming increases

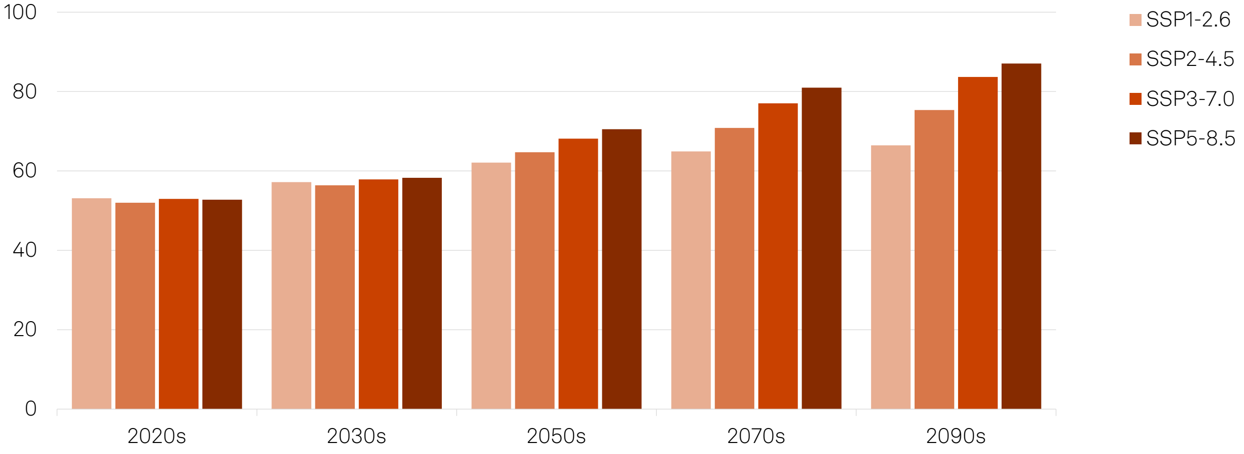
Physical climate risks are increasing in frequency and/or severity in many parts of the world. The associated economic losses will likely also rise with time, particularly if efforts to mitigate greenhouse gas emissions and scale up adaptation and resilience investments are not accelerated (see "Investments In Climate Adaptation Needs Have High Returns On Growth," Jan. 10, 2024).

The S1 dataset suggests that the average exposure of the 95 rated non-U.S. subnational regions to all climate hazards will increase under more severe warming scenarios, absent adaptation (see chart 1). We base this conclusion on the composite exposure score, which is an average of the exposure scores of the nine climate hazards for each decade from the 2020s to the end of the century. Exposure increases by a little over one-quarter (26%) across all scenarios and time points by the 2050s, and by nearly half (48%) by 2100.

Chart 1

Exposure to worsening climate hazards increases with time and more warming

Averaged composite exposure scores under all four climate scenarios among rated regions, decadal averages



Note: Composite exposure score is calculated as an equally-weighted additive combination of the physical risk score of each hazard for a locality for a given scenario and year, which is then rescaled to a 1-100 range using an exponential scoring curve. Sources: S&P Global Ratings, S&P Global Sustainable1.

Most Regions Will Be Hotter And Drier, Others Wetter

Many subnational regions outside the U.S. are already exposed to extreme heat and are projected to remain so through the 2050s. The S1 dataset indicates that temperatures will rise gradually through the end of the century across such regions. For the extreme heat hazard, the S1 dataset defines extreme heat conditions as temperatures exceeding the local daily maximum temperature for 5% of all days in 1950-1999. Our analysis therefore focuses on the frequency of extreme heat days per year that might be expected as the climate warms.

Extreme heat: Regions in Brazil and Mexico feature prominently

Subnational regions outside the U.S. with the highest current exposure to extreme heat are projected to experience the greatest change in days of extreme heat.

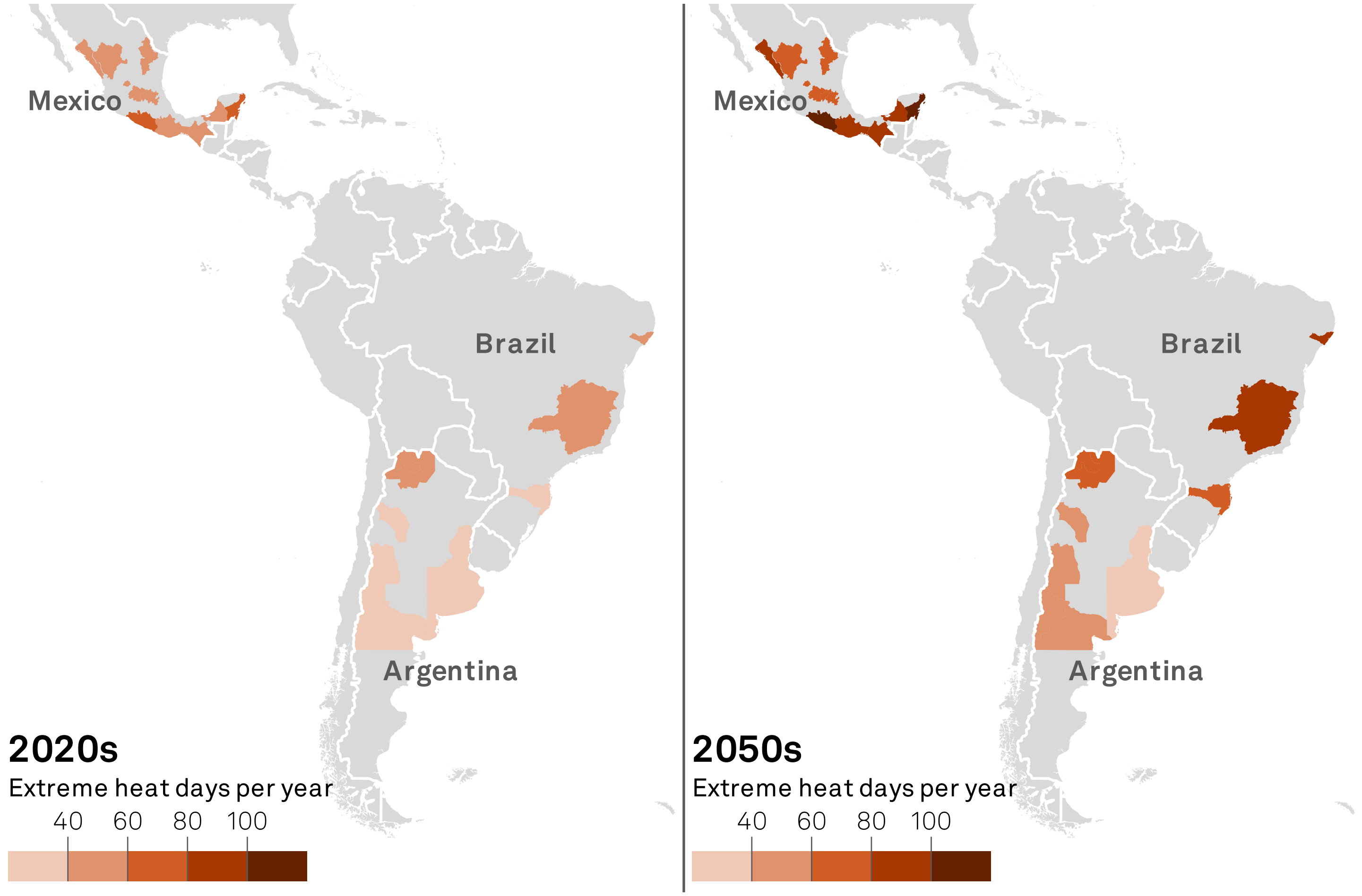
These are primarily in Latin America, in particular Brazil and Mexico, which could experience extreme heat for more than three months of the year by the 2050s (see chart 2). Within Mexico, mainly regions in the south face exposure to extreme heat events, with an average of 56 days of extreme heat a year in the 2020s, increasing to about 100 days in the 2050s. Sarawak in Malaysia is an outlier among non-U.S. subnational regions in terms of heat exposure, with 74 days of extreme heat per year projected in 2050, an increase of more than 57% from 47 days per year in the 2020s. Other regions in Malaysia are also projected to experience extreme heat conditions for more than six months of the year by the 2050s under SSP3-7.0.

Overall, however, for the 95 rated non-U.S. subnational regions, the average number of days per year with extreme heat conditions is about 64, versus 88 for the global dataset; the most exposed regions are projected to experience extreme heat conditions for more than 10 months a year by the 2050s.

Chart 2

Extreme heat exposure in the 2050s is highest in Mexican and Brazilian subnational regions

Days with temperatures exceeding the 95th percentile among rated regions, decadal averages



Note: the extreme heat hazard is defined as the annual percentage of days with maximum temperature warmer than the 95th percentile local baseline (1950-1999) daily maximum temperature. Sources: S&P Global Sustainable1, S&P Global Ratings.

The slow-transition scenario (SSP3-7.0) does not appear to affect heat exposure materially in the short term but does so by the midcentury. Across all scenarios, most regions will experience similar extreme heat conditions until the end of the current decade. This trend is expected to diverge by the 2050s, though the ranking of the 95 subnational regions by exposure stays mostly consistent. In Mexican regions, in particular, compared with the moderate emissions scenario (SSP2-4.5), a slow transition (SSP3-7.0) results in an additional 20 days of extreme heat.

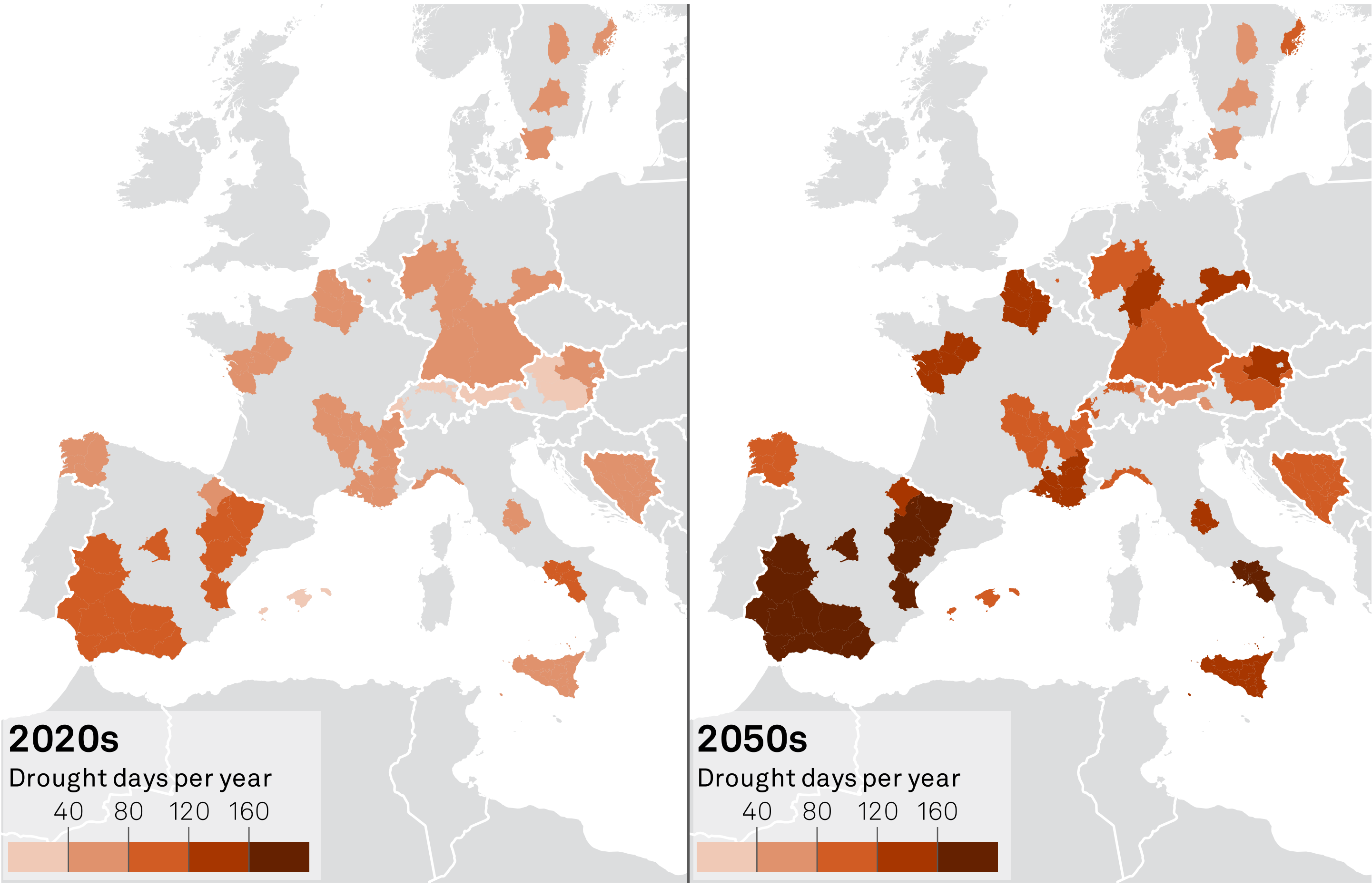
Drought: Conditions could worsen, particularly in southern Europe and Latin America

Exposure to drought conditions are projected to increase across subnational regions, including where drought is already common.

Chart 3

Some European regions could see six months of drought conditions per year by the 2050s

Days with moderate-to-extreme drought conditions by rated subnational region under SSP3-7.0, decadal averages



Note: the drought hazard is derived from the Standardized Precipitation and Evapotranspiration Index (SPEI), taking into account daily solar radiation and daily surface wind speed, in addition to projected changes in temperature and precipitation. The hazard variable is the average proportion of months per annum classified as severely dry or extremely dry based on SPEI--values converted to days per year in this chart. Sources: S&P Global Sustainable1, S&P Global Ratings.

More than half (55% or 53) of the 95 subnational regions outside the U.S. could experience more than three months of moderate-to-extreme drought by the 2050s under a slow transition (SSP3-7.0) (see chart 3)**.** In the 2020s, the number is only four (4%). The more extreme drought exposure is concentrated in southern Europe, particularly Spain and Italy, with two regions in Spain projected to experience drought conditions for more than six months per year by the 2050s. Regions in Argentina and Australia will remain highly exposed to drought. The incidence of drought is projected to increase faster than for other hazards, particularly for Mexican subnational regions, where the number of drought days could more than triple by 2050 under SSP3-7.0, a finding echoed by other research (see "How Climate Change Is Exacerbating Drought Risks," Sept. 17, 2024). More severe drought conditions are also projected in Spain, New Zealand, and parts of central Europe (Austria and Switzerland) among subnational regions we rate.

Water stress exposure is high for some of these subnational regions, but conditions remain stable over time. About one-quarter (23 of 95) are exposed to medium-to-high water stress (an exposure value greater than 50 out of 100, where 100 denotes the highest exposure). Some regions in Mexico, Italy, and Spain are extremely exposed to water stress, with exposure values of 95 to 100. These regions, like others in the dataset, are already highly exposed and do not see any significant increase in exposure over time, and large increases in drought exposure are not reflected in the projected water stress values for 2050. These exposure values do not take into account any adaptation measures LRGs may have in place to lessen the potential impacts of water shortages.

Wildfires: High and relatively stable exposure, with a few hot spots

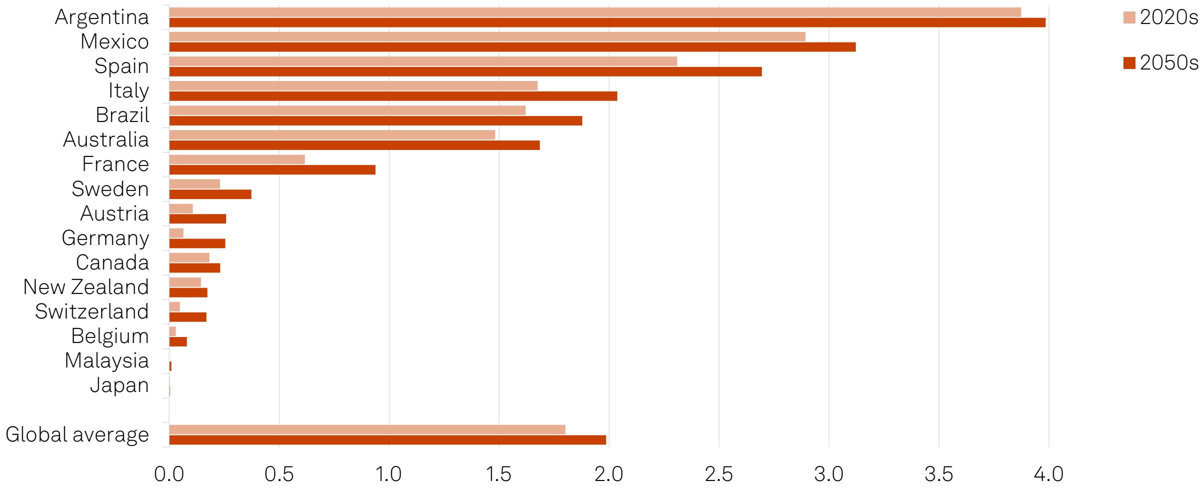
Under all scenarios, the 95 subnational regions' wildfire exposure remains fairly stable, particularly in areas already highly exposed. High-to-extreme wildfire conditions are projected to be present in 17 subnational regions for at least three months of the year in the 2020s under a slow transition scenario (SSP3-7.0). This value remains steady through the 2050s.

The majority of subnational regions in our study that are already experiencing high-to-extreme wildfire conditions are in Latin America, primarily Argentina and Mexico (see chart 4). The rest are in southern Europe. Five rated Latin American subnational regions could experience more than five months of elevated wildfire conditions each year by the 2050s. Regions with the highest exposure are projected to experience the lowest percentage change in the number of days with high-to-extreme wildfire conditions, meaning that exposure stays consistently high. The number of wildfire days in subnational regions with medium wildfire exposure in the 2020s are shown to increase through the 2050s. This could have implications for the adequacy of current measures to adapt to worsening wildfire conditions. The relatively low rate of change in exposure to wildfire conditions, in comparison to other hazards, is consistent with the global dataset, where locations experience high-to-extreme wildfire conditions almost year-round.

Chart 4

Wildfire exposure remains high but relatively stable

Months where wildfire conditions are high to extreme across countries we rate, under SSP3-7.0, decadal averages



Note: Wildfire Conditions according to the Fire Weather Index. The GDP-weighted methodology includes assigning lower weighting to forested and other rural areas, meaning that some regions where wildfires have historically propagated may not be highlighted in the dataset (for example, some regions in Canada). The hazard variable is the average proportion of days per annum that are classified as high, very high or extreme wildfire danger based on the FWI.
Sources: S&P Global Sustainable1, S&P Global Ratings.

Flooding: Rising sea levels could threaten coastal areas

For the three types of flooding (coastal, pluvial, and fluvial), the S1 dataset provides insights into the projected frequencies at which a 1-in-100-year flood event could occur, under a given climate scenario.

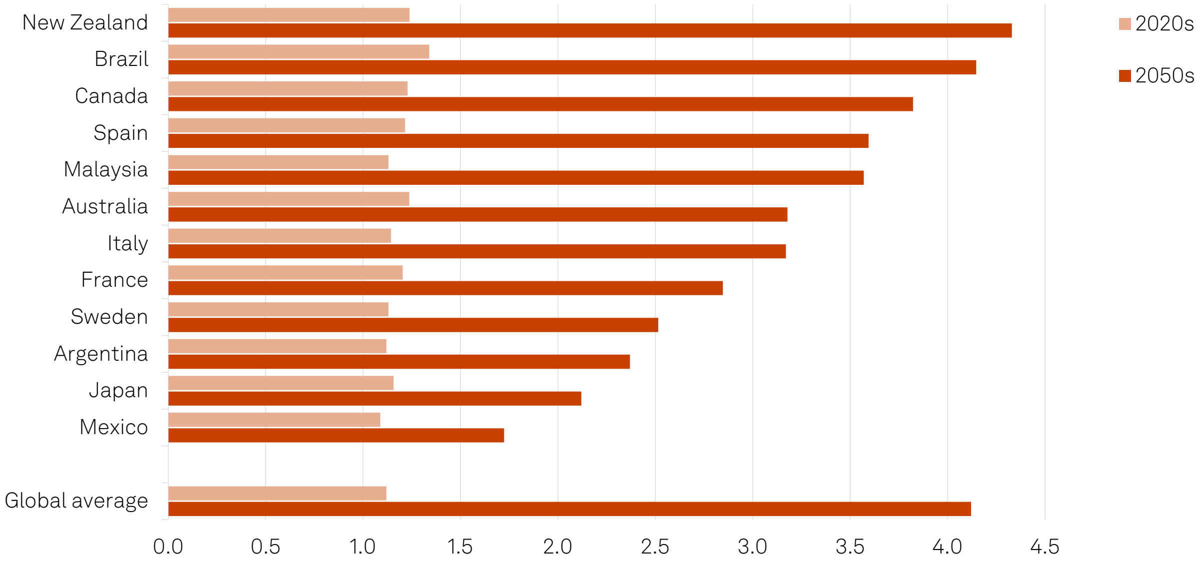
A 1-in-100-year flood event is defined relative to local conditions based on the flood depth reached during similar historical events. Therefore, the extent of flooding captured in the data varies by location. A significant increase in the frequency of a 1-in-100-year flood event does not imply an increase in flood depth if, for example, the 1-in-100-year flood depth is only a few centimeters. Coastal flooding (or extreme pluvial events) could drastically increase the frequency of flooding. The baseline 1-in-100-year flood depth in areas exposed to storms (such as some Mexican and Japanese subnational regions, according to the S1 dataset) may be higher than in other areas due to historical storm surges. This potentially reduces the frequency at which this depth is projected to be exceeded.

Coastal flooding exposure will be more frequent for all coastal subnational regions under all scenarios. This is true for both the 95 rated non-U.S. subnational regions in this study and the wider subnational group in the S1 dataset. In addition, coastal flooding is projected to become more frequent in the wider subnational group than in our sample, including in areas already exposed to major coastal flooding. Among that group, regions in New Zealand and Brazil are most exposed under a slow transition scenario (SSP 3-7.0), with the frequency of coastal floods rising more than 4x by the 2050s (see chart 5). Canadian, Malaysian, and Spanish regions also see significant increases by midcentury. Under a limited mitigation scenario (SSP5-8.5), these same locations are affected, but Italian regions see the greatest increase, with coastal flood frequency rising 5.5x compared to the 2020s. These projected increases in exposure to coastal flooding, combined with the locked-in longer-term impact of greenhouse gas emissions on sea level rise beyond midcentury, could put pressure on LRGs to solidify existing or planned adaptation and resilience measures.

Chart 5

Coastal flood exposure increases significantly across multiple subnational regions by 2050

Subnational coastal flood frequency (1-in-100-year flood depth) across countries we rate, under SSP3-7.0, decadal averages



Note: Global average values do not include locations with zero coastal flood values.
Sources: S&P Global Sustainable1, S&P Global Ratings.

Alongside coastal flooding, more frequent fluvial and/or pluvial flood events could also threaten many subnational regions outside the U.S., notably those in New Zealand, Canada, Japan, and Malaysia. Different types of flooding could occur at the same time, possibly triggered by the same meteorological event (for example, tropical or subtropical storms), putting additional strain on resources used for response efforts and necessitating enhanced adaptation efforts to withstand future events.

Compound climate hazards increase the potential for economic losses

The co-occurrence of climate hazards is becoming more likely as the climate changes and weather events become increasingly frequent. Climate events that occur consecutively--for example, drought followed by heavy rainfall--can lead to flooding, may exacerbate economic losses beyond the sum of their parts, and hamper recovery efforts. The flooding in Pakistan in 2022, which was caused by heavier-than-usual monsoon rains and a severe heat wave, is a recent example. We have previously described how the non-linearity of impacts can challenge countries' economic growth (see "Is Climate Change Another Obstacle To Economic Development?," Jan. 16, 2023).

Some compound climate hazards have become more likely because of climate change. This is according to the findings of Ridder et al. (2020) when looking at the joint occurrence of climate hazards between 1980 and 2014. The combination of hazards includes, but is not limited to, water stress and extreme heat, and wildfire and extreme heat. While there is still significant uncertainty regarding the timing and manifestation of impacts following physical climate risk events (among other dynamics), our analysis provides a forward-looking view on the potential rising co-occurrence of compound events.

Compound climate hazards are also more likely to occur in regions already highly exposed to physical climate risks. In our previous research "Lost GDP: Potential Impacts Of Physical Climate Risks," Nov. 27, 2023, we found that extreme heat and water stress become more pronounced in most global regions, and that exposure to all compound hazards is rising across Asia. Those findings remain consistent with those for the 95 subnational regions we rate outside the U.S.

Across much of southern Spain and Italy, as well as Mexico, water stress and extreme heat represent compound climate hazards that are projected to increase in frequency (see chart 6). In combination, these compound events may contribute to depletion of water resources, increased energy demand, disruption to agricultural production, and a greater risk of wildfires. We have previously described the rising threat posed by reduced water availability in Mexico, finding that 20 of 32 states could face high exposure to water stress by 2050, up from 11 today (see "More Mexican States Could Face Water Stress By 2050," April 4, 2023).

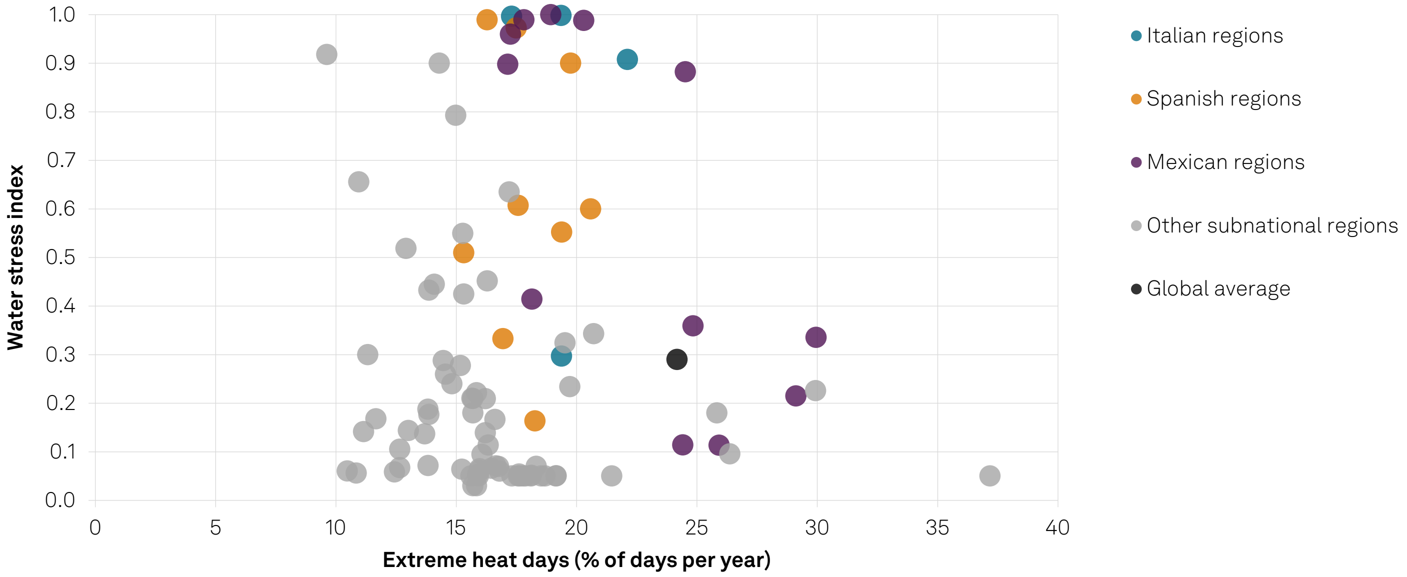
The combined impacts of more frequent wildfires and days of extreme heat expose subnational regions in Latin America the most. By 2050, more than one-third (35%) or 33 of the 95 rated subnational regions are projected to be exposed to more than six weeks of extreme heat days and wildfire conditions under a slow transition scenario (SSP3-7.0). Higher average and extreme temperatures during wildfire events can contribute to sustained wildfire conditions, owing to low soil moisture content and low humidity. Subnational regions in Brazil and Mexico are projected to be exposed to three months of extreme heat days and high wildfire likelihood days under the same scenario and timepoint (see chart 7). In August 2021, extreme heat and drought conditions led to a spike in wildfire activity in the Amazon rainforest, destroying thousands of hectares of forest. In Mexico, a number of severe wildfire events--exacerbated by hot and dry conditions--have affected southern states, including Sonora in 2021 and Oaxaca in 2019, damaging property and forests.

By 2050, more than one-third (35%) or 33 of the 95 rated subnational regions are projected to be exposed to more than six weeks of extreme heat days and wildfire conditions under a slow transition scenario (SSP3-7.0)

Chart 6

Several subnational regions face outsize exposure to compound effects of extreme heat and water stress

Water stress versus extreme heat under a slow transition scenario, 2050s

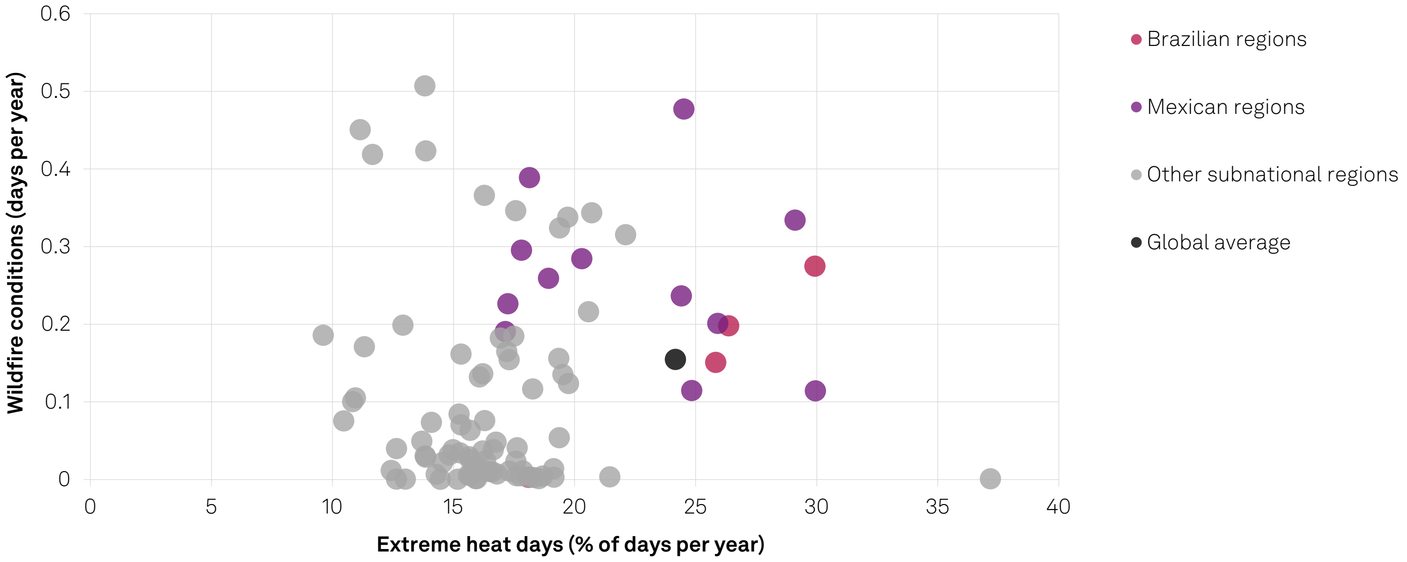


Note: Water Stress Index is the ratio of total water withdrawals within an area to the available water resources in surface and groundwater. Values above 0.4 are considered high stress. Extreme heat days are measured as the percentage of days per year with a maximum temperature that exceeds the 95th percentile of the local historical baseline daily maximum temperature. Sources: S&P Global Sustainable1, S&P Global Ratings.

Chart 7

Several subnational regions face outsize exposure to compound effects of extreme heat and wildfire

Wildfire conditions versus extreme heat under a slow transition scenario, 2050s



Note: Wildfire hazard is defined based on the Fire Weather Index of the Canadian Forest Fire Danger Rating System, and assesses if meteorological conditions are favorable for wildfire development--projected frequency of days per year classified as high, very high and extreme. Extreme heat days are measured as the percentage of days per year with a maximum temperature that exceeds the 95th percentile of the local historical baseline daily maximum temperature. Sources: S&P Global Sustainable1, S&P Global Ratings.

Physical Climate Risks Can Be A Consideration For Credit Ratings

Assessing potential rating impacts from physical climate risk for LRGs outside the U.S. is rooted in our methodology (see "ESG Principles in Credit Ratings," Oct. 10, 2021) and our sector-specific criteria. Together, these allow us to analyze the issuer's ability to pay its financial obligations on time and in full.

Local and regional governments can be exposed to worsening climate hazards

Physical climate risks can affect the creditworthiness of LRGs where the risk cannot be adapted to. For example, extreme climate hazards such as cyclonic storms and heavy precipitation that lead to flooding are likely the most acute risks. Extreme heat can reduce productivity and result in more indirect impacts on the subnational region's economy and population growth.

The way that physical climate risks may influence the creditworthiness of LRGs outside the U.S. could vary. Impacts can be either direct or indirect and/or emerge over varying timescales.

- **Direct impacts:** These can manifest through infrastructure and asset damage and/or disruption to operations (including unexpected or increased operating costs), and result in higher-than-expected investments to rebuild (and adapt) housing, roads, bridges, dams, sewage systems, and buildings. Chronic changes--such as water or heat stress--may require development of alternate water supply resources or reduce workforce productivity. They may also require building-material modifications to withstand longer periods of increasing extreme heat conditions.
- **Indirect impacts:** These may materialize as even greater financial risks--such as higher amounts or greater costs of debt and increased insurance premiums and/or reduced coverage. Furthermore, economic and/or demographic changes could result from exposure to physical climate risk. These trends could stretch governments' financial resources (such as property, income, or sales tax collection). Planning for infrastructure investments through adaptation may reduce these potential indirect risks, if and when they materialize.

The physical impacts from climate hazards can weigh more on the credit quality of some LRGs than others. This may be reflected in the government's capacity to serve its population, respond to service demands, and prioritize resources to protect its economic base from the acute and chronic impacts of climate change. In the long term, these impacts, in turn, can affect fiscal sustainability, economic development efforts, and the ability or inability to implement revenue enhancements when necessary. LRGs' management teams may balance physical risk exposures with addressing the needs and costs associated with adapting to them.

Risk management actions can be a consideration in our view of management planning. When material and relevant, we incorporate policies and practices into our overall assessment of creditworthiness. The impact of climate hazards on LRGs' creditworthiness may also depend to a large extent on the ability and willingness of their respective central governments to help shoulder the costs of adapting to and managing these risks. Central governments, particularly in developed countries, typically provide strong support in the event of natural catastrophes, and they may also devote resources to help LRGs invest in adaptation efforts. Supranational organizations, such as the European Union, may also provide financial support to significantly reduce the burden on individual LRGs to address such challenges.

Key considerations when assessing an LRG's creditworthiness

The following analytical considerations also contribute to the assessment of an LRG's creditworthiness:

Underlying credit fundamentals. As noted in our research, "Lost GDP: Potential Impacts Of Physical Climate Risks," published Nov. 27, 2023, the strength of the economy and of national institutions is a key credit factor for sovereigns in responding and adapting to physical climate risk exposure. Other key considerations that apply to LRGs include the supportiveness of the institutional framework under which subnational governments operate and the prudency and effectiveness of their financial management (see chart 8).

Chart 8

We may consider physical climate risk exposures in our analysis, when material and relevant

Financial strength

This includes revenue diversity and available reserves. Financial strength can help LRGs withstand the potential credit impacts of natural disasters and finance ongoing infrastructure improvements to mitigate the acute impacts of physical climate risks.

Debt capacity

This helps determine the affordability of financing long-term solutions to rising chronic risks. These include rising sea levels and water stress.

Management and governance

This can be underpinned by proactive planning for resiliency that could mitigate the impacts of physical climate risks. Furthermore, we observe that local governments that collaborate with other levels of government to drive regional resiliency projects and secure resources, such as grants, could maintain credit quality in the face of physical climate risks.

Economy

This includes the more immediate impact of discrete climate events, such as pluvial flooding, that damage key infrastructure and disrupt the whole economy. A temporary decline in productivity would likely not materially affect creditworthiness within a supportive institutional framework. Nevertheless, for a country with fewer resources, lacking insurance claims payouts, or no emergency funding from the central government or supranational bodies, a negative impact on creditworthiness could be more likely. Longer-term shifts in climate patterns, such as extreme drought and water stress, could also hurt an LRG's economy over time, particularly in regions that rely on industries highly sensitive to climate risk, such as the water-intensive agriculture sector or tourism.

Adaptation efforts, when material and relevant. These may be assessed as part of our financial management analysis. We observe that LRGs we rate outside the U.S. are increasingly adapting to the physical impacts of climate change (see chart 9).

Chart 9

Examples of local and regional governments' planning and adaptation

Financial	**Structural**	**Institutional**	**Social**
Bolstering liquidity to cover initial costs associated with an acute event as well as maintain operations and ensure timely payment of debt service costs	Considering different temperature warming scenarios to help inform infrastructure adequacy, such as sea walls for coastal flooding and stormwater facilities for inland flooding	Updating land use policies to limit development in chronic flood-prone areas	Engaging in business continuity planning to prepare for an acute event

Source: S&P Global Ratings.

Looking Ahead

Climate data and scenario analysis can provide greater visibility about physical climate risks subnational regions outside the U.S. face in the long term. We found in this research that almost all such regions are likely to experience worsening climate hazards, and potentially compound climate events, by 2050 under almost all SSPs. Without adaptation or resilience measures, this could increase credit risks.

Where we view risks as material, we may consider an LRG's specific risk exposures, including those from physical climate risks--either qualitatively or quantitatively--depending on the visibility and expected time horizon that the risk may materialize. This may help us determine the relative influence of these risks on credit factors. Our analysis may also reflect our view of how each LRG is preparing for the impact of climate-related hazards. Furthermore, given the uncertainties of climate change and resulting physical impacts, our analysis may also reflect how an LRG is modifying its capital or financial plans to address longer-term risks and implications.

Contacts

Authors

Paul Munday
London
paul.munday
@spglobal.com

Bhavini Patel
Toronto
bhavini.patel
@spglobal.com

Alejandro Rodriguez Anglada
Madrid
alejandro.rodriguez.anglada
@spglobal.com

Contributors

Zoe Parker
London

Felix Ejgel
London

Carolina Caballero
Sao Paulo

Lisa Schineller
New York

Sabrina Rivers
New York

Nora Wittstruck
New York

Fernanda Nieto
Mexico City

Didre Schneider
Frankfurt

Dhruv Roy
Dubai

Benjamin Young
Dubai

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Editor

Bernadette Stroeder

Designers

Tom Lowenstein
Jonathan Paul Lalgee

Related Research

- How Climate Change Is Exacerbating Drought Risks, Sep. 17, 2024
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Appendix

This section provides an overview of the S&P Global Sustainable1 Country and Subnational Climate Physical Risk dataset. Limitations are described thereafter.

Exposure thresholds

Table A1 describes the exposure thresholds used to calculate percent GDP and population exposed to each climate hazard.

Table A1

Thresholds for each climate hazard

Climate hazard	Type	Threshold	Rationale
Extreme heat	Annual percentage of days with maximum temperature warmer than the 95th percentile local baseline daily maximum temperature	0.246	Equivalent to three months of extreme heat days
Coastal flooding	Projected frequency of the historical baseline 100-year coastal flood depth	0.01	A 1% annual probability of a 1 in 100-year flood in exposed areas
Drought	Projected frequency of months classified as moderate drought, severe drought, or extreme drought based on the Standardized Precipitation Evapotranspiration Index (SPEI)	0.246	Equivalent to three months of high drought likelihood days
Fluvial (river) flooding	Projected frequency and extent of the historical baseline 100-year flood depth	0.01	A 1% annual probability of a 1 in 100-year flood in exposed areas
Pluvial (rainfall) flooding	Projected frequency of the historical baseline 100-year daily precipitation rate	0.02	A 2% annual probability of a once in a century flood
Tropical cyclones	Projected annual frequency of category 3 and higher tropical cyclones	0	All exposure to category 3 and higher tropical cyclones is considered material
Water stress	Projected future ratio of water withdrawals to total renewable water supply in a given area	0.4	High water stress as defined by the Fire Weather Index (FWI) Aqueduct dataset
Wildfires	Projected frequency of days classified as high, very high or extreme based on the Fire Weather Index (FWI). Adjusted for land cover/presence of burnable vegetation	0.246	Equivalent to three months of high wildfire likelihood days

Subnational entities included in the S1 dataset

Table A2

Rated subnational entities

Global region	Country	Rated entity
East Asia and Pacific	Australia	Australian Capital Territory (Government of)
East Asia and Pacific	Australia	New South Wales (State of)
East Asia and Pacific	Australia	Queensland (State of)
East Asia and Pacific	Australia	South Australia (State of)
East Asia and Pacific	Australia	Tasmania (State of)
East Asia and Pacific	Australia	Victoria (State of)
East Asia and Pacific	Australia	Western Australia (State of)

Global region	Country	Rated entity
East Asia and Pacific	Japan	Aichi (Prefecture of)
East Asia and Pacific	Japan	Osaka (City of)
East Asia and Pacific	Japan	Tokyo Metropolitan Government
East Asia and Pacific	Malaysia	State of Sarawak
East Asia and Pacific	New Zealand	Auckland Council
East Asia and Pacific	New Zealand	Bay Of Plenty Regional Council
East Asia and Pacific	New Zealand	Marlborough District Council
East Asia and Pacific	New Zealand	South Taranaki District Council
East Asia and Pacific	New Zealand	Tasman District Council
East Asia and Pacific	New Zealand	Greater Wellington Regional Council
Europe	Austria	Burgenland (State of)
Europe	Austria	Lower Austria (State of)
Europe	Austria	Styria (State of)
Europe	Austria	Tyrol (State of)
Europe	Austria	Upper Austria (State of)
Europe	Austria	Vorarlberg (State of)
Europe	Belgium	Brussels-Capital (Region of)
Europe	Bosnia and Herzegovina	Federation of Bosnia and Herzegovina
Europe	Bosnia and Herzegovina	Republika Srpska
Europe	France	Auvergne-Rhone-Alpes (Region of)
Europe	France	Hauts-de-France
Europe	France	Pays de la Loire (Region of)
Europe	France	Provence-Alpes-Cote d'Azur (Region of)
Europe	Germany	Baden-Wuerttemberg (State of)
Europe	Germany	Bavaria (State of)
Europe	Germany	Hesse (State of)
Europe	Germany	North Rhine-Westphalia (State of)
Europe	Germany	Saxony (State of)
Europe	Italy	Campania (Region of)
Europe	Italy	Liguria (Region of)
Europe	Italy	Sicily (Region of)
Europe	Italy	Umbria (Region of)
Europe	Spain	Andalusia (Autonomous Community of)
Europe	Spain	Aragon (Autonomous Community of)
Europe	Spain	Madrid (Autonomous Community of)
Europe	Spain	Navarre (Autonomous Community of)
Europe	Spain	Valencia (Autonomous Community of)
Europe	Spain	Extremadura (Autonomous Community of)
Europe	Spain	Galicia (Autonomous Community of)
Europe	Spain	Balearic Islands (Autonomous Community of) (The)

Global region	Country	Rated entity
Europe	Spain	Canary Islands (Autonomous Community of)
Europe	Sweden	Jonkoping (Municipality of)
Europe	Sweden	Orebro (Municipality of)
Europe	Sweden	Skane (Region of)
Europe	Sweden	Stockholm (Region of)
Europe	Switzerland	Aargau (Canton of)
Europe	Switzerland	Basel-Country (Canton of)
Europe	Switzerland	Basel-City (Canton of)
Europe	Switzerland	Geneva (Republic and Canton of)
Europe	Switzerland	St. Gallen (Canton of)
Europe	Switzerland	Solothurn (Canton of)
Europe	Switzerland	Vaud (Canton of)
Europe	Switzerland	Zurich (Canton of)
Latin America and Caribbean	Argentina	Buenos Aires (Province of)
Latin America and Caribbean	Argentina	Entre Rios (Province of)
Latin America and Caribbean	Argentina	Jujuy (Province of)
Latin America and Caribbean	Argentina	La Rioja (Province of)
Latin America and Caribbean	Argentina	Mendoza (Province of)
Latin America and Caribbean	Argentina	Neuquen (Province of)
Latin America and Caribbean	Argentina	Salta (Province of)
Latin America and Caribbean	Argentina	Rio Negro (Province of)
Latin America and Caribbean	Brazil	Alagoas (State of)
Latin America and Caribbean	Brazil	Minas Gerais (State of)
Latin America and Caribbean	Brazil	Santa Catarina (State of)
Latin America and Caribbean	Brazil	Paraiba (State of)
Latin America and Caribbean	Mexico	Aguascalientes (State of)
Latin America and Caribbean	Mexico	State of Campeche
Latin America and Caribbean	Mexico	State of Chiapas
Latin America and Caribbean	Mexico	State of Durango
Latin America and Caribbean	Mexico	Guanajuato (State of)
Latin America and Caribbean	Mexico	State of Guerrero
Latin America and Caribbean	Mexico	State of Hidalgo
Latin America and Caribbean	Mexico	State of Nuevo Leon
Latin America and Caribbean	Mexico	State of Oaxaca
Latin America and Caribbean	Mexico	Queretaro Arteaga (State of)
Latin America and Caribbean	Mexico	State of Quintana Roo
Latin America and Caribbean	Mexico	State of Sinaloa
North America	Canada	Alberta (Province of)
North America	Canada	British Columbia (Province of)
North America	Canada	Manitoba (Province of)

Global region	Country	Rated entity
North America	Canada	New Brunswick (Province of)
North America	Canada	Newfoundland and Labrador (Province of)
North America	Canada	Nova Scotia (Province of)
North America	Canada	Ontario (Province of)
North America	Canada	Prince Edward Island (Province of)
North America	Canada	Quebec (Province of)
North America	Canada	Saskatchewan (Province of)
North America	Canada	Yukon (Territory of)

Limitations

We describe some of the limitations and assumptions of our analysis below. This list is not exhaustive.

The climate hazard metrics capture exposure to physical climate risks only. This is separate from vulnerability, which can depend on the subnational region's socioeconomic footprint, industry sector spatial distribution, trade linkages, and supply chains, among other factors. This is also distinct from value at risk of associated economic factors, such as GDP, tax base, human capital, property value, infrastructure, or transit systems, for example. The exposure hazard data is a first step only toward understanding the diverse range of factors that may contribute to (or offset) the climate-related credit impairment of an issuer/instrument--such as adaptation and resilience measures (for example, levees, green roofs, and managed retreats).

There are certain inherent uncertainties associated with climate science, as is the case for any long-term estimate of future events**.** These include the crystallization and severity of climate risks (see "Model Behavior: How Enhanced Climate Risk Analytics Can Better Serve Financial Market Participants," published June 24, 2021, which describes some of these uncertainties and potential mitigants). These uncertainties may include, but are not limited to:

- **Complexities associated with climate hazards.** The causes of wildfires may be natural, for example, lightning or ignition of dry vegetation by the sun; or human, such as unattended campfires. Many other factors contribute to the number of wildfires in an area in any given year, including how high summer temperatures are, how low precipitation is, and wind conditions. Research suggests a strong relationship between temperature and fire extent, particularly in the U.S., with warmer years generally having greater fire extent (principally due to fuel aridity) than relatively cooler ones, since the early 1980s. While the long-term change in climate that may increase the risk of wildfire events is relatively visible, it is not possible to precisely predict where and when specific wildfire events will happen and what damage they may cause. By their nature, wildfires (like heavy summer rainfall events in many parts of the world) are highly localized. Notwithstanding this, the potential increasing exposure over time highlights the importance of dialogue and learning about how LRGs within these areas consider these risks and whether they have measures in place to reduce wildfire risk.
- **Modelling highly localized events**. Wildfires and other events are challenging to model because local conditions (including topography and wind patterns) are not easily replicated at scale in global climate models. It is currently a challenge to model changing wind patterns (which can fuel wildfire intensity) in wildfire projections with the available science. Model limitations could obscure some of the likely changes in intensity that may happen over the next 30 years.

- **Climate hazard thresholds**. S&P Global Sustainable1 defines hazard metrics using climate extremes, and recognizes hazard thresholds of major magnitude in the measurement of GDP and population exposed, to ensure the capture of significant climate trend developments beyond natural variability. Differences in the vulnerability of specific locations are likely to mean that significant impacts exist at hazard levels beyond the extremes and thresholds defined. A review of literature by S&P Global Sustainable1 did not identify any literature that would define the basis for the thresholds.
- **Cascading and/or multi-climate hazards are not considered.** All hazards are modeled independently, and correlation or vulnerability associated with the co-occurrence of multiple hazards is not currently specifically modelled. For example, the tropical cyclone hazard metric encompasses the frequency of associated wind risks, while the coastal flooding hazard metric independently includes storm surge flooding, likely capturing flooding associated with tropical cyclones.

In addition, other limitations include, but are not limited to:

- **Focus on productive areas**. Regional hazard metrics have been calculated using GDP to weight cell hazard inputs for computing representative regional averages.
- **The GDP and population datasets are historical and do not capture future changes in economic or population geography**. The datasets used to represent the distribution of population and GDP are historical and are held constant in the future scenario projections. We project the distribution of population and the production of GDP will change with time as economies and communities develop, and these changes will not be reflected in the metrics presented in this dataset.

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