Measuring What Matters: A New Approach to Assessing Sovereign Climate Risk

Four Twenty Seven developed a new methodology to assess sovereign physical climate risk exposure based on the population, Gross Domestic Product (GDP) Purchasing Power Parity (PPP), and agricultural area exposed to floods, heat stress, hurricanes and typhoons, sea level rise, water stress, and wildfires.

By 2040, we project the number of people exposed to damaging floods will rise from 2.2 billion to 3.6 billion people, or from 28% to 41% of the global population. Roughly $78 trillion, equivalent to about 57% of the world's current GDP, will be exposed to flooding.

Over 25% of the world’s population in 2040 could be in areas where the frequency and severity of hot days far exceeds local historical extremes, with negative implications for human health, labor productivity, and agriculture. In some areas of Latin America, climate change will expose 80-100% of agriculture to increased heat stress in 2040.

By 2040, we estimate over a third of today’s agricultural area will be subject to high water stress. In Africa, over 125 million people and over 35 million hectares of agriculture will be exposed to increased water stress, threatening regional food security.

By 2040, nearly a third of the world’s population may live in areas where the meteorological conditions and vegetative fuel availability would allow for wildfires to spread if ignited.

Over half of the population in the most exposed small island developing nations are exposed to either cyclones or coastal flooding amplified by sea level rise. In the United States and China alone, over $10 trillion worth of GDP (PPP) is exposed to hurricanes and typhoons.
INTRODUCTION

Increasingly severe climate conditions impose growing pressure on populations and economies around the world. The implications on economic growth, welfare, production, labor, and productivity are large, with potential material impacts on sovereign credit risk. To date there has been no granular, globally comparable assessment mapping physical climate risk exposure to the most economically productive and populated areas of a country.

Four Twenty Seven’s new sovereign climate risk data provides detailed analytics that focus on key risk drivers for countries, measuring the amount of agriculture area, future population, and future GDP (PPP) exposed to climate hazards. This new climate risk data can help deepen the understanding of sovereign and country climate risk for investors and credit institutions. It can also be used to identify areas most in need of adaptation finance and to prioritize resilience investments.

Textbox 1: From Climate Risks to Credit Risks

If no action is taken to address vulnerability to climate risks, the implications for credit risks will be significant, increasing financial instability and limiting long-term economic growth opportunities for highly exposed countries. Moody’s Investors Service (MIS) notes in its Request for Comment on “General Principles for Assessing Environmental, Social and Governance Risks Methodology” how it would consider the credit implications of environmental, social and governance issues. The MIS Sovereign Group considers the “likelihood that events related to physical climate risks will occur and have a negative and lasting impact on a sovereign’s economy, finances or balance of payments.” MIS typically also considers a country’s specific characteristics that indicate lower or higher sensitivity to these risks. Sensitivity primarily depends on the share of weather-dependent economic activities (e.g., agriculture and tourism), the quality of infrastructure and health care systems, and, for sovereigns exposed to sea level rise, the share of the population living close to sea levels. For example, an outsized concentration of economic activities in locations exposed to sea level rise is likely to worsen assessment of a sovereign’s overall physical climate risk.

Research by the Centre for Sustainable Finance at SOAS University of London, the Asian Development Bank Institute, the World Wide Fund for Nature Singapore, and Four Twenty Seven demonstrates new empirical evidence that sovereign climate risk increases the cost of capital and further explores these risk pathways, by identifying six transmission channels:

- fiscal impacts of climate-related natural disasters;
- fiscal consequences of adaptation and mitigation activities;
- macroeconomic impacts of climate change;
- climate-related risks and financial sector stability;
- impacts on international trade and capital flows;
- impacts on political stability.

1Moody’s. 2018. Credit profiles of small, agriculture-reliant sovereigns most susceptible to climate change risk. Sector In-depth, 15 May. New York, NY: Moody’s Investors Service
CHALLENGES WITH ASSESSING SOVEREIGN CLIMATE RISK

Most approaches quantifying future climate risk for sovereigns seek to measure the average exposure over the territory of the country. There are two major limitations with this approach:

First, measuring exposure over a territory does not provide an accurate picture of whether the populated or economically productive areas are exposed to climate extremes. The average impact of climate change over the entire country will differ greatly from impacts felt in the most populated areas. Furthermore, extreme, unpopulated environments (e.g. water bodies, barren land and desert) may skew results, showing extreme exposure that does not represent the exposure of populated areas.

Second, measuring climate risk in aggregate may misrepresent risk, in particular for large countries such as China, Russia, and the United States. Extremes in one area of the country are washed out when averaging across the entire country, and a single measure of climate risk for such countries grossly underrepresents the diversity of hazards. Similarly, indices aggregating exposure to several hazards can fail to represent the fact that large swaths of small tropical countries can be almost entirely exposed to extremes such as hurricanes or heat stress, even if they are less exposed to other hazards.

Sovereign climate risk assessments have not typically integrated a view on who and what are exposed to specific hazards within a country because hazard data and exposure data capturing the location of populations or economic productivity have generally been unavailable or too coarse to be useful. This data has become available in recent years, which allows us to map the co-occurrence of hazards and exposures, explicitly factoring in the spatial heterogeneity of both climate hazards and people and economic activities across a country. Our methodology is described in Textbox 2.

Textbox 2: Methodology

Our methodology allows us to assess socioeconomic climate risk by projecting the percentage of people, GDP (PPP), and agriculture exposed to dangerous levels of climate risk. We assess climate risk by intersecting six physical hazard layers, including floods, heat stress, hurricanes & typhoons, sea level rise, water stress, and wildfires, with three maps including projected population (2040), projected GDP (in 2005 US$, adjusted for purchasing power parity, PPP), and current agricultural area. The spatial resolution of these datasets is illustrated in Figure 1.

For wildfire, temperature, and precipitation-based indicators, we use outputs from the NASA NEX-GDDP project, a statistically downscaled dataset of Coupled Model Intercomparison Project Phase 5. Indicator results are based on an ensemble average of 18 models, comparing the period of 1975-2005 and 2030-2040 based on the highest emission pathway, known as Representative Concentration Pathway (RCP) 8.5. For floods, hurricanes, sea level rise, and water stress we also leverage other environmental datasets to capture different dimensions of

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3 We use representative concentration pathway (RCP) 8.5 for our timeframe of analysis, the decade 2030-2040, because regardless of policy changes today to mitigate greenhouse gas emissions we are locked into some physical climate impacts due to the residence time of greenhouse gases in the atmosphere and understanding the potential scale of these impacts will help inform preparedness. The outcomes of different RCPs do not diverge significantly until after mid-century. Please see our analysis “Demystifying Climate Scenario Analysis for Financial Stakeholders” for more details. (Steinberg, N, Gannon, G., and Turner, J., “Demystifying Climate Scenario Analysis for Financial Stakeholders,” December 2019, Four Twenty Seven, http://427mt.com/wp-content/uploads/2019/12/Demystifying-Scenario-Analysis_427_2019.pdf).
risk. These include water stress data from the World Resources Institute Aqueduct tool and hurricane data from the World Meteorological Organization. For floods we use historical and simulated flood data considering high resolution elevation data and data on regional flood infrastructure from our partner, Fathom, a flood analytics firm.

We identify areas as high risk to each hazard if they meet the following criteria:

- **Floods**: Exposed to at least 0.2 meter of flooding during a 1-in-100 year pluvial or fluvial flood event
- **Heat Stress**: Exposed to relatively high changes in temperature extremes compared to global average
- **Hurricanes & Typhoons**: Situated in the regular path of cyclones
- **Sea Level Rise**: Exposed to at least some shoreline flooding during a 1-in-100-year coastal flood event
- **Water Stress**: Already has high water stress, or water supplies are diminishing and/or competition is expected to increase
- **Wildfires**: Has high wildfire potential with sizable increases in future wildfire potential severity and high-risk days

To generate our scores, we first identify populated areas of a country that have high exposure to each climate hazard (Fig. 1), and then identify the total and relative portion of population, GDP (PPP), and agricultural area in these highly exposed areas. We bin the final scores into five risk thresholds ranging from “none” to “very high” risk. By incorporating both total and relative exposure, our scores provide investors with a sense of the raw amounts of social and economic capital within a sovereign that should be safeguarded against climate hazards, as well as the sovereign’s potential ability to absorb and recover from climate shocks and stresses.
KEY FINDINGS

Global Socioeconomic Exposure

Globally, the level of socioeconomic exposure to climate risk is alarming. We find that flood and water stress may affect around 40% of both the global population and the global economy by 2040. Approximately 8% of the world’s economy is expected to be subject to coastal flooding amplified by sea level rise, equivalent to $17 trillion USD. Many of these areas are exposed to more than one risk, such that heat extremes and drought-like conditions or sea level rise and hurricanes and typhoons tend to occur together, increasing the likelihood of impacts for these regions.

Figure 2. The percent of GDP (PPP), agricultural area, and population exposed to each hazard globally. © Four Twenty Seven. All Rights Reserved.

Table 1. Total and relative global socioeconomic exposure to high climate risk © Four Twenty Seven. All Rights Reserved.

<table>
<thead>
<tr>
<th>Climate Hazard</th>
<th>Population at High Risk (Billions)</th>
<th>GDP (PPP) at High Risk (Trillion USD)</th>
<th>Agriculture Area at High Risk (100 million hectares)</th>
<th>Global Percentage of Population at High Risk</th>
<th>Global Percentage of GDP (PPP) at High Risk</th>
<th>Global Percentage of Agriculture Area at High Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooding</td>
<td>3.6</td>
<td>78</td>
<td>7.9</td>
<td>41%</td>
<td>43%</td>
<td>26%</td>
</tr>
<tr>
<td>Heat Stress</td>
<td>2.4</td>
<td>41</td>
<td>9.1</td>
<td>28%</td>
<td>23%</td>
<td>31%</td>
</tr>
<tr>
<td>Hurricanes &amp; Typhoons</td>
<td>0.6</td>
<td>20</td>
<td>0.8</td>
<td>7.2%</td>
<td>11%</td>
<td>3.1%</td>
</tr>
<tr>
<td>Sea Level Rise</td>
<td>0.3</td>
<td>17</td>
<td>0.1</td>
<td>2.9%</td>
<td>9%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Water Stress</td>
<td>3.4</td>
<td>72</td>
<td>10.4</td>
<td>39%</td>
<td>40%</td>
<td>35%</td>
</tr>
<tr>
<td>Wildfires</td>
<td>2.6</td>
<td>41</td>
<td>7.3</td>
<td>30%</td>
<td>22%</td>
<td>24%</td>
</tr>
</tbody>
</table>
Two-thirds of all sovereigns we evaluated are highly exposed to at least one climate hazard deemed “high” or “very high” risk, and nearly half of all sovereigns are exposed to two or more hazards (Fig. 3). We also find that wealthier countries, in terms of GDP per capita, are just as likely as poorer countries to be affected by multiple climate hazards. Although wealthier countries may have more resources to allocate towards adaptation, this underscores the need for risk identification and resilience investment in all countries. We also find that climate hazards are correlated, even when aggregated to the sovereign level. For example, sovereigns that are highly exposed to sea level rise are also likely to be vulnerable to cyclones and an increased risk of heat stress is associated with higher exposure to water stress. These interactions depend upon many factors such as the season and the region.

When two hazards happen simultaneously or one soon after another, their impacts are typically exacerbated because response resources are already stretched thin. Governments can demonstrate increased preparedness for climate impacts by recognizing and accounting for these multivariate risks in planning adaptation and resilience investments.

**Floods**

Today, over one-quarter of the world’s population, about 2.2 billion people, live in locations that are estimated to experience some level of inundation during a 1-in-100-year flood event.\(^9\) We find that by 2040, the number of people living in areas susceptible to damaging floods may rise to 3.6 billion people or 41% of the global population (Table 1).

Roughly 78 trillion $USD, equivalent to about 57% of the world’s current GDP (PPP) is situated along flood-prone coastlines, riverways, and low-lying deltas. These high concentrations of wealth and labor were born out of the necessity to establish commerce and trade centers near waterways, though they place a large swath of future generations and their economies directly in the way of floodwaters. The countries with the highest exposure to flooding are Indonesia, Thailand, the Philippines, Myanmar, Malaysia, and Viet Nam – all countries in Southeast Asia.

Recent history shows flooding is already one of the most destructive climate hazards. Flooding affected ~2.5 billion people from 1994-2013 and was responsible for 50% of all deaths from natural disasters during that time period.\(^10,11\) The World Bank forecasts that global losses due to flooding could rise from $6 billion per year in 2005 to $52 billion a year by 2050 due to population change and urbanization alone—

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which climate change will only worsen.12

**Water Stress**

The world’s food production areas are also highly exposed to climate hazards. We find that by 2040, over a third of today’s agricultural area will likely be subject to high water stress (Table 1). Climate-driven reductions in water supply and population-driven increases in water demand are increasingly leading towards more fierce competition over water resources.13 Many of these water-stressed regions, which we discuss more in the *Regional Case Studies* section, are situated in low-income countries where both food exports and domestic food security are a prerequisite to a minimum standard of living. The United Arab Emirates, Iran, Singapore, Saudi Arabia, and Israel have the highest water stress scores, with each having between 94-100% of its population, GDP (PPP), and agricultural land exposed to water stress.

**Heat Stress**

Temperature extremes are widely recognized as a key risk for growing economies,14 sectors reliant on outdoor labor,15 and even overall firm performance.16 Yet, over one-quarter of the world’s population in 2040 could be living in areas where the frequency and severity of hot days far exceeds local historical extremes (Table 1). While the most exposed countries tend to be in Africa and the Middle East, heat stress will place pressure on people outside of these regions as well. In Europe and South America we find that Italy, Romania, Slovenia, Bulgaria, Albania, Colombia, Venezuela, Bolivia, Peru, and Guyana will each have 80-100% of its population exposed to heat stress by 2040, with severe implications for public health.

In India, 82 million people will be exposed, which is significant because as much as 75% of India’s labor force make their livelihoods outdoors in physically demanding construction and farming jobs.17 Other studies have found that temperature-induced reduction in labor productivity could decrease global incomes by roughly 23% by 2100.18

**Wildfires**

While wildfires may still be rare today in many regions, we find that climatological trends are projected to increase wildfire potential for much of the globe, creating new risks for some countries and increasing the challenge for communities already prone to wildfire. We find that by 2040 nearly a third of the world’s population will be living in areas where the meteorological conditions and vegetative fuel availability would allow for wildfires to spread if ignited (Table 1). Guatemala, Venezuela, Zambia, Mexico, The Democratic Republic of the Congo, and Indonesia are among the most exposed countries to wildfires and each will have 70-100% of their population and GDP exposed to higher wildfire potential in the future.

**Sea Level Rise**

Sea levels are rising globally and placing both human and economic capital at risk. Roughly 10% of the world's population lives in coastal areas below 10 meters of elevation, and 59% of all global trade by value

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is transported via maritime ports. When looking at the percent of people that are exposed to sea level rise, we unsurprisingly find that small island nations are particularly exposed. For example, in the Marshall Islands, Maldives, Kiribati, and Tuvalu, we find that 80-100% of people are highly exposed to sea level rise. However, while sea level rise is often thought of as a small island challenge, larger nations are not immune to the effects. The top five most exposed countries by the total number of exposed people are China, India, Indonesia, the United States, and the Philippines. Together, there are 110 million people and $6 trillion of GDP (PPP) exposed across these countries.

Sovereign Climate Risk

The sovereigns with the highest exposure scores are those that have high exposure both in absolute terms and in terms of the percentage exposed: the Philippines, China, the United States, Mexico and Viet Nam. Note that our scores are uncorrelated with GDP per capita.

Table 2. Top five most exposed countries to climate risk in 2040, by hazard. © Four Twenty Seven. All Rights Reserved.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Total Exposure</th>
<th>Flooding</th>
<th>Heat Stress</th>
<th>Hurricanes &amp; Typhoons</th>
<th>Sea Level Rise</th>
<th>Water Stress</th>
<th>Wildfires</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Philippines</td>
<td>Indonesia</td>
<td>Saudi Arabia</td>
<td>Taiwan</td>
<td>Hong Kong</td>
<td>UAE</td>
<td>Hong Kong</td>
</tr>
<tr>
<td>2</td>
<td>China</td>
<td>Thailand</td>
<td>UAE</td>
<td>Japan</td>
<td>Japan</td>
<td>Iran</td>
<td>Guatemala</td>
</tr>
<tr>
<td>3</td>
<td>United States</td>
<td>Philippines</td>
<td>Egypt</td>
<td>Hong Kong</td>
<td>Singapore</td>
<td>Singapore</td>
<td>Venezuela</td>
</tr>
<tr>
<td>4</td>
<td>Mexico</td>
<td>Myanmar</td>
<td>Angola</td>
<td>Mauritius</td>
<td>Philippines</td>
<td>Saudi Arabia</td>
<td>Zambia</td>
</tr>
<tr>
<td>5</td>
<td>Viet Nam</td>
<td>Malaysia</td>
<td>Israel</td>
<td>Philippines</td>
<td>Taiwan</td>
<td>Israel</td>
<td>Mexico</td>
</tr>
</tbody>
</table>

Figure 4. Sovereign climate risk. Sovereigns are colored based on their overall climate risk exposure in 2040, with the darker red countries being the most exposed. Visit our website to explore an interactive map. © Four Twenty Seven. All Rights Reserved.


We find the Sovereign Climate Score is uncorrelated with GDP per-capita (-0.15) and only weakly correlated with GDP (-0.48) in a Spearman rank correlation.
Regional Case Studies

Heat Stress, Agriculture, and Forced Migration in Central America

In some areas of Latin America, 80-100% of agricultural area will be exposed to increased heat stress in 2040 (Fig. 5). What were previously considered extreme temperatures will become more regular occurrences, further stressing agricultural production that has been pushed to its breaking point in recent years by drought. Guatemala, Honduras and Mexico, in Central America’s Dry Corridor, have 99%, 95%, and 77% of their agricultural area exposed to high heat stress respectively. The large agricultural labor pools in these countries makes this exposure particularly significant as it could threaten the health of agricultural workers as well as agricultural yields and food security.

Increased heat stress will likely exacerbate both the internal and external climate migration trends that have been ongoing throughout Latin America. In South America, over 17 million people (2.6% of the region’s population) could migrate internally by 2050, testing the capacity of health, housing, and social support systems in South America. Buenos Aires, Rio de Janeiro, Sao Paulo, Belo Horizonte, Bogota, and Lima are already classified as “megacities” with populations over 10 million people, where the urban heat island effect will exacerbate high temperatures, as paved areas with little green space absorb excess heat. As the population increases, so too will the number of informal settlements on the outskirts of cities. These settlements tend to lack basic infrastructure and services and are often concentrated in low-lying areas prone to other climate hazards such as flooding or landslides. Relief efforts following such hazards can reduce budget reserves and increased competition for housing and social resources can negatively impact political stability.

Figure 5. Layering of high resolution land cover dataset (a) with projected future heat stress (b) to identify the percent of agriculture highly exposed to heat stress in Latin America on a per-country basis. © Four Twenty Seven. All Rights Reserved.

**Water Stress, Livelihoods, and Food Security in Africa**

Climate models project that warmer temperatures will redistribute precipitation around the globe such that, in general, dry areas will become drier, and wet areas will become wetter. Our results indicate that these patterns will lead to even greater water stress in regions such as North Africa and the Near East that already struggle with water supplies; although significant desalination developments seen in the Near East may help mitigate risk in that region. In North Africa, the per-capita freshwater availability has decreased by two-thirds over the last 40 years, and climate models indicate that this trend may continue (Fig. 6). Intersecting areas of high future water stress with socioeconomic data, we find that over 125 million people, over 35 million hectares of agriculture, and over $1.98 trillion in GDP (PPP) will be exposed to increased water stress in the future.

While several of these countries do have significant desalination infrastructure, Morocco, Algeria, Libya, Tunisia, and the entirety of the Near East will all have more than 90% of their population, agriculture, and GDP exposed. The effect on agriculture may be particularly pronounced, as 60% of African food production comes from non-irrigated agriculture that is highly dependent on annual rainfall. Agriculture is a significant contributor to African economies, employment, and food supplies. Over 100 million people in Africa have been affected by droughts in the last 30 years, and chronic undernourishment affects over 10% of the population in Near East and North Africa. As water resources have been developed to their limit in North Africa, there are opportunities to reduce water withdrawals by investing in water efficiency measures throughout agro-processing and food supply chains.

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25Food and Agriculture Organization of the United Nations. (2008). Resources and challenges in the context of climate change. In Water for agriculture and energy in Africa: The challenges of climate change (pp. 93–99)

**Flooding in Asia**

While shifting precipitation patterns lead to further drying in the subtropics, increased precipitation in tropic regions already prone to heavy rainfall, such as Southeast Asia, is expected to significantly increase the frequency and severity of flooding. This will exacerbate an ongoing problem that already disrupts global supply chains and, by 2040, may threaten up to 1 billion people in Asia. The Pearl River Delta in Southern China (Fig. 7), an area that is home to over 100 million people and responsible for 10% of China’s GDP and 20% of its foreign direct investment, experienced devastating floods in 2014 that inundated hundreds of factories and destroyed tens of thousands of homes. We find that 49% of China's GDP (PPP) will be at high risk of flooding by 2040, while 41% of its population will be at risk.

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**Figure 7.** Global map of population exposed to 1-in-100 year floods with inundation levels greater than 0.2m. East Asia has the greatest levels of exposure. There are over 10 million people exposed to flooding in the Pearl River Delta (outlined by the black box) alone. The zoom on the black box shows an overlay of high resolution population data in the Pearl River Delta (a) with modeled flood inundation levels in meters (b) to determine the amount of the population currently exposed to a 1-in-100 year flood event (c). © Four Twenty Seven. All Rights Reserved.

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In October 2020, Laos, Vietnam, and Cambodia were inundated by heavy rainfall, resulting in the displacement of over 40,000 people, over 121,000 submerged homes, over 200,000 hectares of flooded land, and hundreds of deaths.\(^\text{30}\) We find that nearly 50% of agricultural area in Cambodia, Vietnam and Laos will be exposed to flooding by 2040 and 70%, 67% and 49% respectively of their populations will also be exposed to floods. The exposure to floods and heavy rainfall in these areas means that such severe events may occur more often, or when they do occur, they will bring more inundation than historical floods, which will affect national budgeting, the tax base, and risk management practices.

**Sea Level Rise Along the Eastern United States**

Climate change-induced glacial melt and thermal expansion of the oceans are causing sea levels to rise globally, threatening low-lying coastal areas. Sea levels have risen around 8-9 inches over the last 140 years, but the rate has accelerated, with a full third of the total change occurring over the last 25 years.\(^\text{31}\)

Sea level rise has many negative effects ranging from increased high-tide flooding to deadlier hurricane storm surges. While a small portion of total land area globally is exposed to sea level rise, countries like the United States (Fig. 8) that have a significant concentration of population and economic capital along their coastal lines are particularly vulnerable.

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Figure 8. High resolution map of U.S. population exposed to sea level rise. Brighter colors indicate higher population densities, and areas covered in blue are those that may experience flooding from sea level rise in the future. The zoomed in area shows the intersection of population data with sea level rise exposure models. All bars represent 1km x 1km areas highly exposed to sea level rise, and those with greater peak heights and redder colors indicate higher population densities. © Four Twenty Seven. All Rights Reserved.
coastlines are particularly vulnerable. In the United States $8.3 trillion (35% of U.S. GDP) and 150 million people (40% of total projected population) are concentrated within 5km of the coast. We find that 16 million people and $2.3 trillion are highly exposed to sea level rise by 2040, equivalent to 10% of the total US GDP (PPP).

Miami, New York, New Orleans, and Boston are among the most exposed cities in the world to sea level rise, and hundreds of millions of dollars are already disappearing from the Florida real estate market as high-tide flooding encroaches farther inland.

Furthermore, high-tide flooding is expected to increase by 5- to 15-fold by 2050. This will lead to stranded assets that may not be permanently inundated but experience systematic flooding that renders them unreliable or too costly to repair.

**Storms and Small Island Nations**

Due to the relationship between warm air and hurricane strength, storms are expected to increase in their intensity and/or frequency as climate change warms sea surface temperatures. This is likely already occurring, as recent hurricanes have retained their destructive power for longer than historical storms after making landfall. The countries with the highest relative exposure to hurricanes and typhoons are island nations in the Caribbean and South China Seas which lie directly in the path of historical storm tracts (Fig. 9). One hundred percent of the population and economic activity is exposed in smaller nations such as Grenada, Trinidad & Tobago, Barbados, St. Vincent and the Grenadines, St. Lucia, Dominica, Antigua and Barbuda, Haiti, the Dominican Republic, and Taiwan. Larger nations such as the Philippines have lower percent exposure (75-80% of their population and GDP) than other islands, but the exposure is still significant as it equates to $880 billion and 102 million people.

Administrative hurdles, limited labor pools, and supply

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**Figure 9.** Tropical cyclone tracts from 1980-2019 over the Caribbean (a) and the South China Sea (b). Risk classes are assigned according to the frequency and intensity (as measured by maximum wind speed) of historical cyclones. © Four Twenty Seven. All Rights Reserved.

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shortages can significantly delay recovery efforts in large, wealthy nations like the United States, but these issues are exacerbated even further for islands due to their relative geographic isolation. In 2013, one of the largest tropical cyclones ever recorded, Typhoon Haiyan (also known as Super Typhoon Yolanda), passed over the Philippines, causing billions in damages, destroying 500,000 homes, and displacing over 4 million people.

**Wildfires in Mediterranean Climates**

Changes in temperature and precipitation patterns have doubled the amount of area vulnerable to wildfires globally, as well as increased the intensity and length of fire seasons. Our results show that the highest levels of future wildfire risk are centered in tropical and subtropical countries where significant burnable vegetation and susceptibility to hot, dry conditions elevate the potential for fire activity. Generally smaller nations with equatorial and arid climates have a vast majority, if not the entirety, of their agriculture, population, and GDP near areas with high wildfire potential.

However, larger countries with Mediterranean climates also have significant exposure to wildfires (Fig. 10). For example, Portugal has 65% of its agriculture, 44% of its GDP, and 40% of its population exposed to high wildfire potential. This is a country in which long-term social and economic trends exacerbate

In 2017, Hurricane Irma passed over Saint-Marin, an island in the Caribbean along a chain of islands receiving our highest Hurricane & Typhoon hazard scores. Ninety-five percent of the buildings on the island were damaged, and much of the infrastructure remained damaged two years later despite an initial influx of financial support.

![Figure 10](https://example.com/image.png)
levels of climate risk exposure. Matching a trend seen in many nations, young people from rural areas are flocking to cities in search of more economic opportunity. As the agricultural labor force and associated activity shrinks, areas that once served as fire breaks between otherwise unbroken forests are disappearing.\(^{40}\) In 2017, Portugal recorded its largest wildfire on record, burning over 500,000 hectares of land, destroying hundreds of homes, and resulting in over 120 fatalities. Subsequent analysis found that this fire was exacerbated by climactic drivers.\(^{41}\)

Meanwhile, 30% of the Unites States GDP (PPP) and 29% of its population are exposed to increasing wildfire potential. It also has the most total GDP (PPP) exposed to wildfires at $7 trillion. Similar to Spain, socioeconomic factors in highly exposed areas of the United States, such as California, contribute to this increasing exposure. In California, population growth and housing shortages continue to push people and housing development into evermore remote communities where wildfires are more likely, leading to challenging decisions around development, insurability, and who foots the bill when buildings in exposed areas are destroyed.\(^{42}\)

**Textbox 3: Transition Risk**

Transition risks also affect sovereign credit risk. For example, fossil fuel exporters rely on global demand for fossil fuels, often as a significant contribution to their trade balance and domestic income. Thus, global decarbonization policies would present economic risks to these countries. Likewise, countries with high fossil fuel consumption that lack renewable energy will be exposed to increasing energy costs as policies shift. Transition risk data from Moody’s ESG Solutions powered by Moody’s affiliate V.E provides a view on countries’ emissions and their institutional policies for preparing for the transition to a low carbon economy. While this report focuses on physical climate risk exposure, understanding sovereign transition risk alongside physical risk exposure provides a more complete picture of risk.

**BEYOND EXPOSURE**

While our methodology provides a measure of the degree of socioeconomic exposure to a high degree of projected climate risk, it does not include any measure of sensitivity or adaptive capacity, which are central to understanding climate vulnerability. As such, this analysis provides limited insight regarding the extent of vulnerability facing poor households, small businesses, and groups in communities that are more sensitive and less able to cope with climate change’s significant impacts.

It is also important to note that these findings convey risk exposure and not guaranteed loss. The relationships between the size of a climate hazard and corresponding impact on social, cultural, and economic factors is not well-established at a fine enough geospatial scale to be utilized in this analysis. We are therefore unable to draw conclusions about potential losses due to climate change, though we plan to incorporate more impact studies (i.e., country-specific dose-response curves) in future iterations.

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Our approach to evaluating spatially-explicit socio-economic exposure to climate change implicitly places more weight in areas with higher concentrations of people and wealth. As a result, more rural and less populated areas countries are effectively downweighted. These areas may play an important role in future national development or may support important trade and transportation routes that are integral to national economic growth.

There are ample opportunities for future research building from this dataset. In future analyses we plan to provide more granular data on exposure of population, GDP (PPP), and agriculture at a sub-sovereign level. Likewise, we will extend the projection timeframe from 2040 through to the end of the century and incorporate multiple different climate and socioeconomic pathways in future datasets.

CONCLUSION

Sovereign exposure to climate hazards is a topic of much concern globally, but trying to assess exposure to climate risk using a simple average of geographic exposure can misrepresent risk drivers and economic assets at risk. Our novel approach, overlaying climate data with population and GDP (PPP) at a high spatial resolution, provides a more nuanced understanding of how human and economic assets are exposed to future climate impacts at the country level. Our assessment of the exposure of agricultural areas captures critical risks both in terms of food security and global supply chains.

This data demonstrates that there is significant exposure of population, GDP (PPP), and agriculture to physical climate hazards globally. All nations face meaningful risks despite their variation in size and resources. This risk exposure can translate to macroeconomic impacts in many ways, including effects on trade balances, tax bases, public health, labor productivity, and political stability. This analysis highlights that it is impossible to divest from climate risk, a ubiquitous risk which will only spread and worsen over time.

This more granular understanding of risk may inform investment and lending decisions, helping to more accurately price risk and diversify portfolios. It may also help direct adaptation finance flows and target risk mitigation measures. As the potential costs of inaction become clearer, the increased transparency regarding future exposure is important to incentivize greater investments in resilience globally.
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