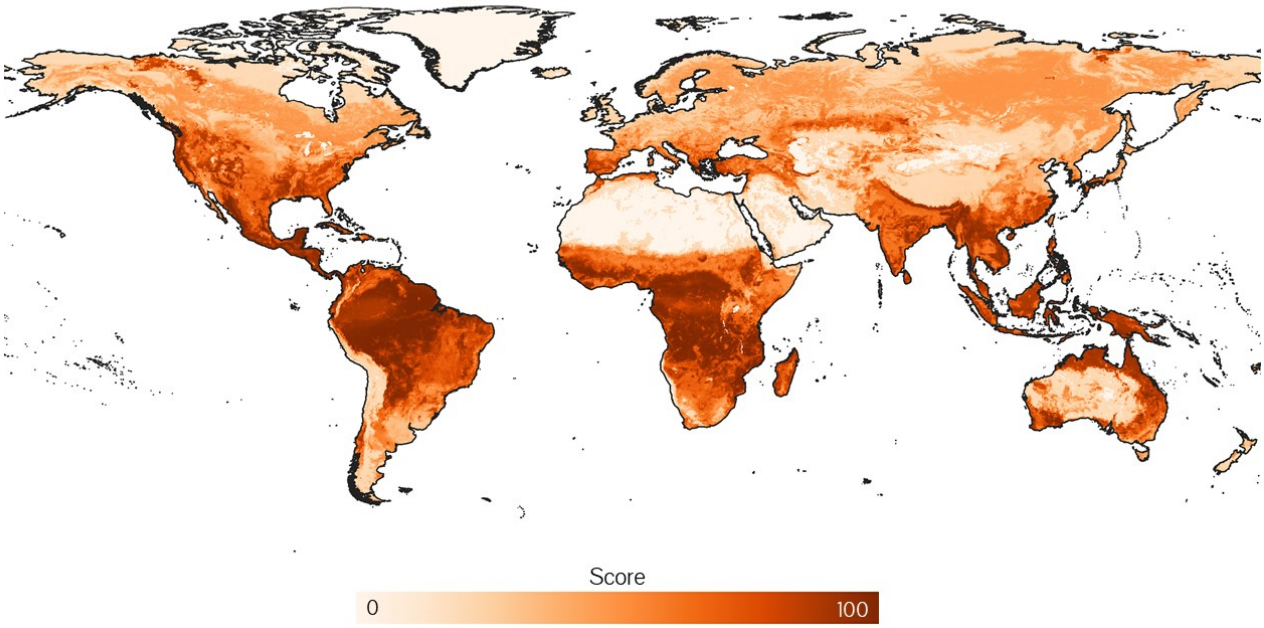
Climate Change and Wildfires: Projecting Future Wildfire Potential



Four Twenty Seven, August 2020

KEY TAKEAWAYS

- Four Twenty Seven developed a first-of-its-kind global dataset projecting changes to wildfire potential under a changing climate, at a granularity of about 25 x25 kilometers.
- In areas already exposed to wildfires, by 2030-2040 climate change will prolong wildfire seasons, adding up to three months of days with high wildfire potential in Western Australia, over two months in regions of northern California and a month in European countries including Spain, Portugal and Greece.
- New wildfire risks will emerge in historically wet and cool regions, such as Siberia, which is projected to have 20 more days of high wildfire potential in 2030-2040.
- Globally, western portions of the Amazon and Southeast Asia will experience the largest relative increases in wildfire severity, further threatening crucial biodiversity hotspots and carbon sinks.
- Confronting this new risk will take unprecedented resources and new approaches in regions not familiar with wildfires and worsening wildfire seasons will continue to threaten already limited resources in currently exposed areas.

INTRODUCTION

Wildfires are complex physical phenomena that come at extraordinary costs to human and natural systems. The 2019-2020 Australian bushfires raged for seven months, killed more than 30 people, hospitalized thousands more,[1] and burned more than 10 million hectares of land.[2] While the full financial and ecological impact is still unknown, costs from those fires are likely to exceed the $4.4 billion record set by Australia's 2009 Black Saturday fires.[3]

Climate change is already making wildfires more severe and is expected to worsen wildfire potential, lengthening seasons in areas already prone to wildfires, and creating hotter and drier conditions that will expose entirely new areas to wildfires.[4] We are already seeing the effects of climate change on wildfires in some regions like the western United States.[5] Ten of the largest wildfires in Arizona's history occurred in the last eight years and nine of California's largest wildfires occurred in just the last seven years.[6] Beyond direct losses and disruption from damage to buildings and infrastructure, air pollution from wildfires has led to healthcare costs in excess of $100 billion in losses per year in the United States.[7] Leaders in government, finance, and public health need to understand how and where climate change will further heighten wildfire potential because of the serious threat wildfires pose to societies, economies, and natural systems.

Wildfire potential refers to meteorological conditions and vegetative fuel sources that are conducive to wildfires. With better information on where wildfire potential is growing, decision-makers can prepare and build resilience in economies, across regions, and at the site-level. Building resilience to wildfires requires not only asset-specific investments like fire-resistant building materials and insurance, but also the more holistic development of fire-adapted communities and regions (see more below in the section *Taking Action*).

Four Twenty Seven's newest analytics highlight key regions exposed to increasing wildfire potential by 2030-2040. Using a proprietary methodology submitted for peer review, our analytics link climate drivers such as changing temperature and precipitation patterns with the availability of vegetative fuels to assess wildfire potential in the future. It is not a probabilistic model for wildfire risk, which would require predictions of when and where ignitions may occur, such as from lightning, a downed power line, or a campfire. Rather, our approach leverages the power of global climate models to evaluate the degree and extent of changing climatic patterns and match those results to high-resolution imagery of land use

[1]Cohen, Li, "Australian bushfire smoke killed more people than the fires did, study says," *CBS News*, March 20, 2020, https://www.cbsnews.com/news/australia-fires-bushfire-smoke-killed-more-people-than-the-fires-did-study-says/.

[2]Rodway, Nick, "'We are a ghost town': Counting the cost of Australia's bushfires," *Aljazeera*, January 27, 2020, https://www.aljazeera.com/ajimpact/ghost-town-counting-cost-australias-bushfires-200127035021168.html.

[3]Ben Butler, "Economic Impact of Australia's Bushfires Set to Exceed $4.4bn Cost of Black Saturday," *The Guardian*, January 7, 2020, https://www.theguardian.com/australia-news/2020/jan/08/economic-impact-of-australias-bushfires-set-to-exceed-44bn-cost-of-black-saturday.

[4]French, Christopher, "America on Fire: Climate Change, Wildfires & Insuring Natural Catastrophes," 54 *U.S. Davis Law Review (Forthcoming),* April 18, 2020, Penn State Law Research Paper No. 11-2020.

[5]John T. Abatzoglou, A. Park Williams, "Climate change has added to western US forest fire," *Proceedings of the National Academy of Sciences* 113, no. 42 (October 2016): p. 11770-11775, https://doi.org/10.1073/pnas.1607171113.

[6]Cappucci, Matthew and Freedman, Andrew, "Arizona wildfires grow as flames flicker throughout Desert Southwest and California," *The Washington Post,* June 22, 2020, https://www.washingtonpost.com/weather/2020/06/22/arizona-wildfires-grow-flames-flicker-throughout-desert-southwest-california/

[7]Fann N., Alman B., Broome R. A., Morgan G. G., Johnston F. H., Pouliot G., & Rappold A. G., "The health impacts and economic value of wildland fire episodes in the U.S.: 2008-2012," *The Science of the Total Environment*, 2018.

types to better understand where these changing patterns could have the greatest impact.

In places where wildfires are already common, this data will help community leaders plan and budget for climate-adaptive infrastructure and bolster resources for public health, important not only for community well-being but also to minimize business disruptions from employee absences and declines in worker productivity in the wake of wildfire events.[8] In places where wildfires represent an emergent threat, like some northern latitudes,[9] officials can reallocate resources to prepare and manage for future change. Investors seeking to build or invest in existing and newly wildfire-prone areas will have a deeper understanding of where their investments are exposed, enabling them to seek further information on how local and state officials are managing for the risk more broadly. Greater awareness of wildfire potential may also provide an incentive for financial and credit institutions to invest in resilience at the building-level through mitigation measures like constructing with wildfire-resistant materials and risk transfer mechanisms like insurance.

ASSESSING WILDFIRE POTENTIAL

Four Twenty Seven uses several indicators to evaluate wildfire potential, developing metrics that describe where conditions are favorable for wildfires to occur. Leveraging outputs from global circulation models (GCMs) under a high emissions scenario,[10] we provide the only known globally comparable dataset that illustrates wildfire potential under climate change at the scale of approximately 25 kilometers by 25 kilometers anywhere on Earth.

Four Twenty Seven's wildfire scores are built upon two key factors: soil moisture deficit and availability of fuel. The interplay between both factors is critical because, while dry conditions driven by warmer temperatures are expected to become more frequent and severe in a changing climate, not all areas will have fuel to burn. Wildfire fuel includes various types of vegetation, like coniferous and deciduous forests, grasslands, shrublands, and agricultural lands. To capture both soil moisture deficit and wildfire fuel, we use the Keetch-Byram Drought Index (KBDI) combined with information on vegetative land cover, assessing where conditions will be favorable to wildfires in a changing climate. KBDI was created by the U.S. Department of Agriculture Forest Service fire control scientist John Keetch and physicist George Byram to link meteorological conditions to wildfire potential.[11] Since its inception in 1968, the index has been continually used by the agency, employed by fire managers in the southeastern United States[12] and included as part of the U.S. National Fire Danger Rating System.[13]

KBDI incorporates climate data from GCMs like changing temperature and precipitation patterns to describe soil moisture deficit. Research and history

[8]Wibbenmeyer, Matthew, "Building Best Practices for Managing Wildfire Smoke," *Resources for the Future*, October 9, 2019, https://www.resourcesmag.org/archives/building-best-practices-managing-wildfire-smoke/.
[9]Rudnitsky, Jake, Kravchenko, Stepan, Warren, Hayley, Pogkas, Demetrios, "The World's Largest Forest Has Been on Fire for Months," *Bloomberg*, August 8, 2019, https://www.bloomberg.com/graphics/2019-siberia-russia-wildfires/.
[10]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 carbon dioxide 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).
[11]John J Keetch and George M Byram, "A Drought Index for Forest Fire Control," *U.S.D.A. Forest Service* SE-38, November 1968, https://www.srs.fs.usda.gov/pubs/rp/rp_se038.pdf.
[12]"KBDI/CSI Introduction," *Virginia Department of Forestry*, November 25, 2014, http://dof.virginia.gov/fire/kbdi.htm.
[13]"Understanding Fire Danger," *U.S. National Park Service*, November 17 2017, https://www.nps.gov/articles/understanding-fire-danger.htm.

consistently demonstrate that hot and dry conditions are conducive to wildfires.[14, 15] In the western United States increasing heat and arid conditions led to the doubling of forest fire area between 1984 – 2015.[16] The KBDI scale captures heat and moisture conditions, ranging from 0 to 800, with lower scores indicating higher levels of soil saturation, and higher scores indicating soil moisture deficits. Figure 1 shows KBDI values and corresponding risk levels.

Figure 1. *Keech-Byram Drought Index (KBDI) values and corresponding risk levels, adapted from Liu, et. al.*[17]

To take into consideration a land area's potential flammability, we combine the KBDI data with data on vegetative land cover, discounting areas like deserts that lack burnable fuel. Figure 2 shows areas with burnable fuel sources in dark green.

Four Twenty Seven's analytics provide measures of absolute wildfire potential as well as relative change in wildfire potential, as summarized in Table 1. The absolute severity measure shows the maximum wildfire potential of an area using the maximum KBDI in the projection period, 2030-2040, weighted by the land area's burnable fuel sources. The absolute frequency measure describes the number of days with high wildfire potential. In addition to the absolute measures, the data describes the relative change in these conditions compared to the historical baseline, highlighting areas that are likely to be underprepared for wildfires, never or rarely having experienced them in the past.

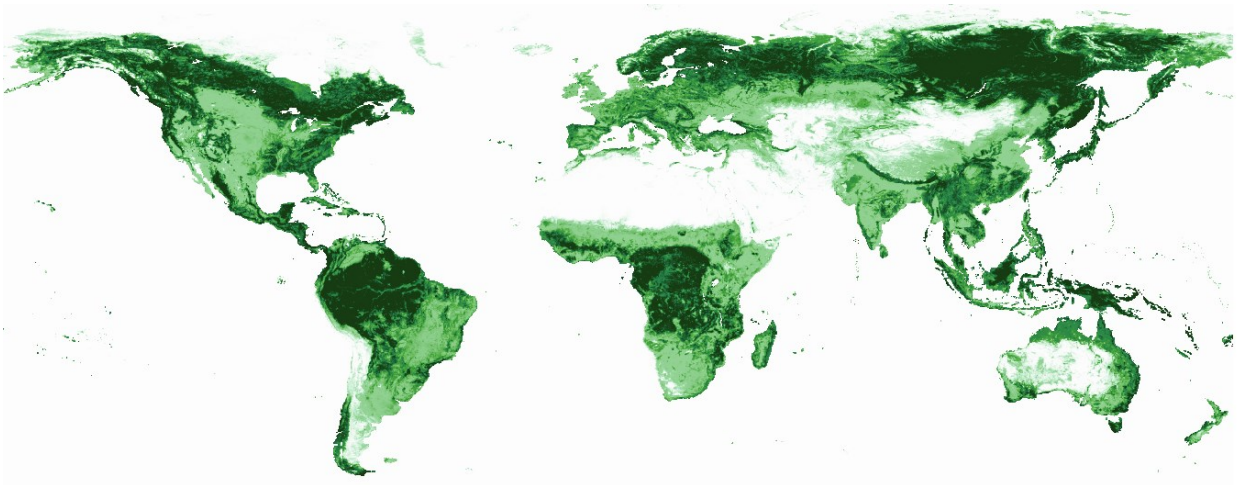


Figure 2. *Representation of land cover with burnable fuel sources used in Four Twenty Seven wildfire scores. Darker areas denote higher levels of burnable fuel sources and lighter areas have lower levels of burnable fuel sources. Source: Four Twenty Seven.*

[14]Mike D. Flannigan et al., "Implications of Changing Climate for Global Wildland Fire," *International Journal of Wildland Fire* 18, no. 5 (2009): p. 483, https://doi.org/10.1071/wf08187.
[15]A. Park Williams et al., "Observed Impacts of Anthropogenic Climate Change on Wildfire in California," *Earth's Future* 7, no. 8 (2019): p. 892-910, https://doi.org/10.1029/2019ef001210.
[16]John T. Abatzoglou, A. Park Williams, "Climate change has added to western US forest fire,"
Proceedings of the National Academy of Sciences 113, no. 42 (October 2016): p. 11770-11775, https://doi.org/10.1073/pnas.1607171113.
[17]Liu, Y., Stanturf, J., and Goodrick, S. "Trends in global wildfire potential in a changing climate," *Forest Ecology and Management* 259, no. 4, (2010): p. 685–697, https://doi.org/10.1016/j.foreco.2009.09.002.

The final wildfire score composed of these indicators shows which areas are exposed to increasing or emerging wildfire potential globally. Four Twenty Seven scores range from 0 to 100, with 0 representing no exposure and 100 representing the most exposed areas globally. Detailed results for each indicator are available as part of our climate risk assessments.

Table 1. *Four Twenty Seven wildfire indicators.*

	Absolute	Relative Difference
Severity	Annual maximum KBDI	Difference in annual maximum KBDI
Frequency	Number of annual high days	Change in number of annual high days

WILDFIRE EXPOSURE BY REGION

Several regions come to mind when thinking about exposure to wildfires globally. Our analytics affirm common understanding about key regions of wildfire exposure, providing an indication of the increasing severity and frequency of wildfires in areas already prone to these events. The analysis also offers insight into areas that may have less obvious exposure, but are likely to have higher wildfire potential over time. Preparing for wildfires is a local, and often regional effort. The relatively high spatial granularity of our results (~25 kilometers) enables decision-makers to evaluate wildfire potential at a useful scale.

Australia

Four Twenty Seven's wildfire metric reveals that areas exposed to wildfires today will continue to be exposed, often with longer periods of high wildfire potential due to changing temperature and precipitation patterns. Wildfires in Western Australia have affected extractive industry facilities, like those in mining and petroleum, in the past, and wildfires could also become more frequent for those facilities adjacent to wildfire-prone areas in the future. Extractive industries constitute the majority of Western Australia's economic output, and the state produces 48% of Australia's total exports.[18]

Some areas in Western Australia could experience up to three additional months per year of conditions with high wildfire potential in 2030-2040. As shown by the darker red areas in Figure 3, the combination of a KBDI that can reach almost the top of the scale and a prevalence of highly burnable vegetation gives sites within this region high wildfire scores. Longer seasons increase the chance of wildfire occurrence in a given year, increase costs to fight wildfires, and leave less down time for communities to recover from fires. With longer wildfire seasons, Australia's reliance on a volunteer firefighting force, often bolstered by support from U.S. and New Zealand firefighters who will experience their own increase in wildfire seasons, is likely to become untenable.[19] The increased wildfire potential could lead to business disruption, power outages, and damage to expensive capital equipment, with negative effects to economic growth in the region.

While Four Twenty Seven analysis shows hot and dry conditions will also prevail in desert areas in the middle of Australia, our inclusion of data on vegetation and land cover weights the exposure scores towards areas that will have both arid conditions and vegetative fuel for wildfires. In addition to Western Australia, regions that emerge as high risk include vegetated portions of the Northern Territory and

[18]"Trade with WA," *Government of Western Australia Department of Jobs, Tourism, Science and Innovation,* https://www.jtsi.wa.gov.au/trade-with-wa

[19]McDonald, Tim, "Australia fires: The huge economic cost of Australia's bushfires," *BBC*, December 20, 2019, https://www.bbc.com/news/business-50862349.

South Australia, and economically important areas in Queensland, Victoria, and New South Wales. In the 2019-2020 bushfire season, Sydney experienced losses estimated between $8.4 million - $35 million (A$ 12 million – A$50 million) per day from lost economic productivity due to transportation disruptions and employees missing work because of illness from wildfire smoke.[20] In January 2020, five months into the seven month-long bushfire season, insurance losses were $685 million (A$995 million).[21]

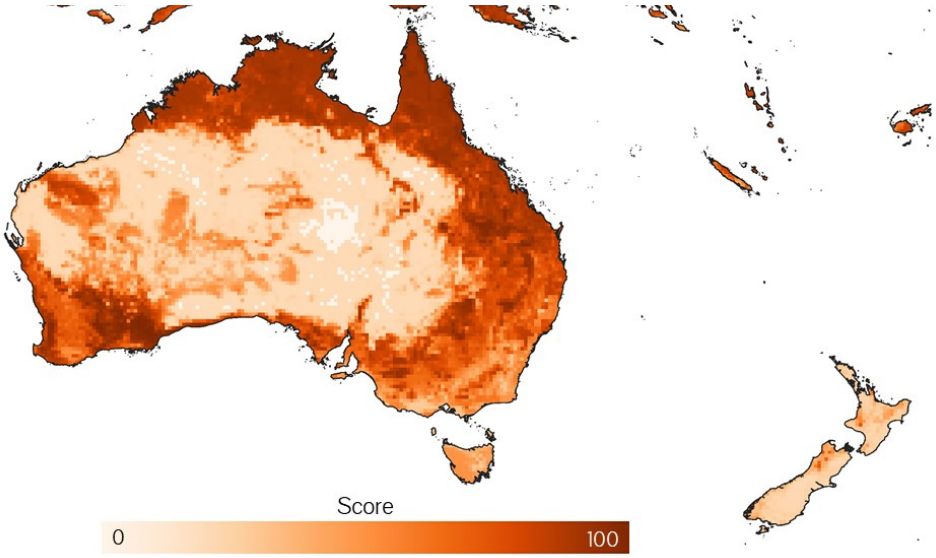


Figure 3. Four Twenty Seven wildfire scores in Australia, with 0 representing no risk and 100 representing high risk.

Brazil

Areas affected by wildfires in 2019 in the western Amazon could see an additional month of days with high wildfire potential by 2040 and areas in the eastern Amazon could see an additional month and a half of days with high wildfire potential relative to the historical baseline. Brazil's government was heavily criticized for its mishandling of the 2019 Amazon wildfires,[22] and the full economic and ecological impacts are still unrealized. The fires will have immense environmental impacts to biodiversity and are also likely to affect several industries that directly rely on raw materials from the Amazon, including timber, cosmetics, and pharmaceuticals. Beyond direct losses in these sectors, political and international trade fallout occurred. Some companies banned Brazilian raw materials from their supply chains, anticipating shifts in consumer preferences from the government's mismanagement of its response to the fires.[23]

Deforestation has increased the prevalence of runaway fires and the lack of governance around logging and agricultural practices combined with the changing climate make the Amazon more vulnerable to wildfires.[24] The trees in the Amazon play a large role in the water cycle needed to keep the rainforest alive. Worsening climate change and more drought-like conditions that can lead to more wildfires, coupled

[20]McDonald, Tim, "Australia fires: The huge economic cost of Australia's bushfires," *BBC News*, December 20, 2019, https://www.bbc.com/news/business-50862349.
[21]Howard, L.S., "Australia's Bushfires Could Surpass 2009's Costly Season; Analysts, Insurers Comment," *Insurance Journal*, January 10, 2020, https://www.insurancejournal.com/news/international/2020/01/10/554271.htm.
[22]"Brazil faces international backlash over Amazon fires, deforestation," *The World*, August 23, 2019, https://www.pri.org/stories/2019-08-23/brazil-faces-international-backlash-over-amazon-fires-deforestation.
[23]Andreoni, Manuela, and Maheshwari, Sapna, "Is Brazilian Leather Out of Fashion? H&M Stops Buying Over Amazon Fires," *New York Times*, September 5, 2019, https://www.nytimes.com/2019/09/05/world/americas/h-m-leather-brazil-amazon-fires.html.
[24]Weisse, Mikaela, and Dow Goldman, Elizabeth, "We Lost a Football Pitch of Primary Rainforest Every 6 Seconds in 2019," *World Resources Institute*, June 2, 2020, https://www.wri.org/blog/2020/06/global-tree-cover-loss-data-2019.

with the effects of deforestation, contribute to a negative cycle of loss of vegetation and reduced rainfall that could cause the Amazon to dwindle or fully disappear.[25] Because this rainforest is such a vital carbon sink, the loss of the Amazon could have unknown and disastrous effects on the global climate and thwart international efforts to mitigate climate change.

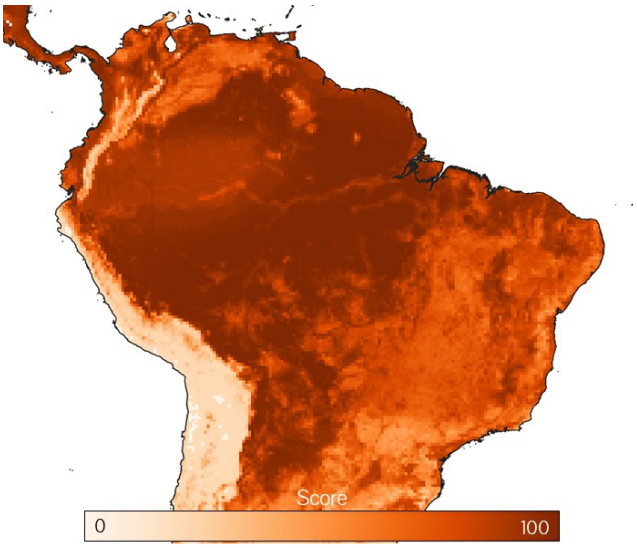


Figure 4. *Four Twenty Seven wildfire scores in the Amazon, with 0 representing no risk and 100 representing high risk.*

Europe

Heat waves, such as the one in 2019 that shattered temperature records across Europe, coincide with the growth in wildfire potential under climate change.[26] Recent wildfires in Europe have had increasing human costs. Amidst a summer heat wave in 2017, the largest wildfire in more than 50 years in Portugal killed more than 60 people,[27] and wildfires that occurred during a heat wave in Greece in 2018 killed more than 75 people.[28] The 2019 heat wave helped contribute to the spread of wildfires in Europe that were 15% larger than the current annual average across this decade.[29] Research on the economic impacts of climate change finds that heat waves and wildfires are among the many extreme weather events that are expected to cause up to 2% of losses to GDP across Europe per year by 2050.[30]

Since 2000, wildfires in Europe have already caused approximately $3.4 billion (€3 billion) in losses per year.[31] Fires in 2019 in Catalonia were the largest in recent decades and struck at the inopportune moment when public health and emergency services were already dealing with the implications of the extremely hot and dry conditions across Europe.[32] In 2030-2040, very arid conditions are projected to prevail in large parts of southern Europe, with high absolute levels of wildfire potential in addition to up to 30 more days with wildfire-favorable conditions per year in Spain. Catalonia is among the most im-

[25]Amigo, Ignacio, "When will the Amazon hit a tipping point?" *Nature*, February 25, 2020, https://www.nature.com/articles/d41586-020-00508-4.
[26]Irfan, Umair, "113 degrees in France: why Europe is so vulnerable to extreme heat," *Vox*, June 28, 2019, https://www.vox.com/world/2019/6/26/18744518/heat-wave-2019-europe-france-germany-spain.
[27]Minder, Raphael, "Portugal Fires Kill More Than 60, Including Drivers Trapped in Cars," *The New York Times*, June 18, 2017, https://www.nytimes.com/2017/06/18/world/europe/portugal-pedrogao-grande-forest-fires.html
[28]Niki Kitsantonis, Richard Pérez-Peña , and Russel Goldman, "In Greece, Wildfires Kill Dozens, Driving Some Into the Sea," *The New York Times*, July 24, 2018, https://www.nytimes.com/2018/07/24/world/europe/greece-fire-deaths.html.
[29]Sengupta, Somini, "How Europe Turned Into a Perfect Landscape for Wildfires," The New York Times, February 5, 2020, https://www.nytimes.com/2020/02/05/climate/forests-europe-climate-changed.html.
[30]Beard, Stephen, "Europe's economy wilts in one of the Continent's hottest heat waves," Marketplace, July 11, 2019, https://www.marketplace.org/2019/07/11/europes-economy-wilts-in-one-of-continents-hottest-heat-waves/.
[31]The Burning Issue: Managing Wildfire Risk," *Oliver Wyman*, September 2019, https://www.oliverwyman.com/content/dam/oliver-wyman/v2/publications/2019/sept/THE%20BURNING%20ISSUE%20-%20MANAGING%20WILDFIRE%20RISK_web.pdf.
[32]Henley, Jon and Jones, Sam, "Spain battles biggest wildfires in 20 years as heatwave grips Europe," *The Guardian*, June 27, 2019, https://www.theguardian.com/world/2019/jun/27/hundreds-of-firefighters-tackle-blaze-in-north-east-spain.

portant economic areas in Spain, accounting for 20% of the country's GDP,[33] with sectors like automobile, chemical, and food manufacturing as well as tourism at risk from direct losses, operations disruptions, and reduced revenues from wildfires.

Tourism remains an important economic driver throughout portions of southern Europe, including areas that will become more vulnerable to wildfires, like Portugal, Spain, and Greece, as shown in Figure 6. Wildfires in Greece in 2018 and 2019 directly hit tourist areas during the peak of the summer holiday season, causing evacuations and travel restrictions at ports used by tour operators.[34,35] The maximum KBDI in some areas of Greece with burnable fuel sources will reach above 500/800 in our timeframe of analysis. As these events happen more frequently and with greater severity, tourists are likely to change their travel destinations over the long term, favoring areas that are less wildfire-prone or that they perceive to be less susceptible.

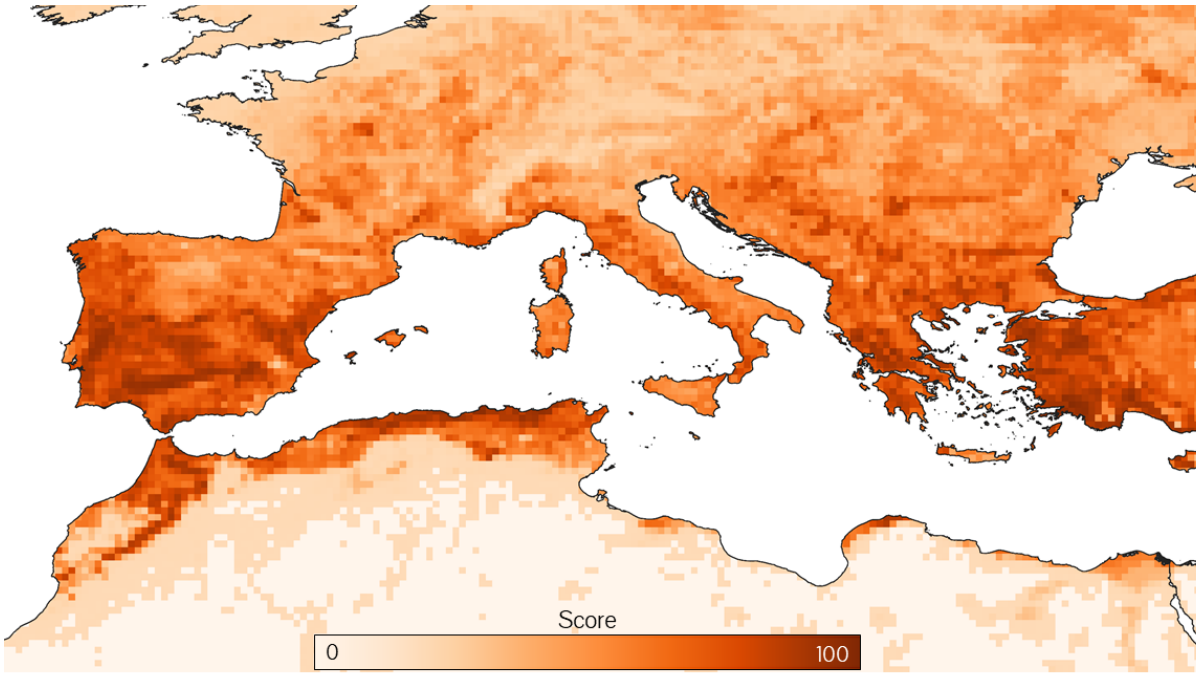


Figure 5. Four Twenty Seven wildfire scores in Europe, with 0 representing no risk and 100 representing high risk.

Siberia

Alarmingly, Four Twenty Seven's wildfire analysis also reveals that areas in far northern latitudes not historically exposed to wildfires will become exposed. These areas are even more vulnerable than those with a history of wildfires, as they are less likely to have measures in place to address this hazard. While seasonal wildfires are common in parts of Siberia, the rate of warming in the Arctic is twice as high as the rest of the globe which contributed to permafrost melting and the wider spread of wildfires in the region in 2019 and 2020.[36] Melting permafrost areas have the potential to contribute to accelerating cli-

[33]"Gross domestic product (GDP) in Catalonia and the whole of Spain between 2003 and 2019," *Statista*, June 2020, https://www.statista.com/statistics/327063/gross-domestic-product-in-catalonia-and-spain/.
[34]Morris, Hugh, "Greece wildfires: Is it safe to travel to Greece?" *The Telegraph*, July 24, 2018, https://www.telegraph.co.uk/travel/destinations/europe/greece/articles/forest-fires-is-it-safe-can-i-cancel-my-holiday/.
[35]Coffey, Helen, "Greece wildfires: hundreds of tourists evacuated from hotels and beaches," *Independent*, August 27, 2019, https://www.independent.co.uk/travel/news-and-advice/greece-wildfires-tourists-evacuated-beach-hotel-samos-island-fire-a9080281.html.
[36]Borunda, Alejandra, "What a 100-degree day in Siberia really means," *National Geographic*, June 23, 2020, https://www.nationalgeographic.com/science/2020/06/what-100-degree-day-siberia-means-climate-change/#close.

mate feedback cycles and runaway warming.[37] Conditions in areas in the Siberian Arctic Circle, normally too wet and icy to be vulnerable to wildfires, became wildfire-prone after record temperatures reached above 100 degrees Fahrenheit in June 2020.[38] Seventeen million hectares of land have burned as of the end of July 2020.[39] In 2019, wildfires in Siberia burned more than 7 million hectares of land, causing smoky conditions in the nearby cities of Krasnoyarsk and Novosibirsk.[40] Soaring temperatures, earlier snowmelt, and dry conditions created perfect wildfire conditions. This trend is expected to persist and worsen. According to Four Twenty Seven analysis, far northern latitudes are expected to have an additional 20 days per year of high wildfire potential days in 2030-2040.

The region lacks the financial resources and experience to fight large wildfires, and its small firefighting force was only able to contain 4% before more resources from the Russian military had to be deployed. A state of emergency covering a region larger than India was declared in July 2019. The 2019 Siberian fires were estimated to have caused $100 million in damages, and as larger areas burn for longer periods of time, wildfires have the potential to have increasing worldwide impacts. Wildfires and drought conditions in 2010 in Russia caused a spike in global commodities prices and required a domestic response to protect citizens against rising prices for basic goods and to avoid political unrest.[41]

Mexico

In central Mexico, economically important areas with manufacturing and industrial sites are expected to experience increased severity and frequency of wildfire potential. As shown in Figure 6 large portions of the country will be highly exposed in 2030-2040.

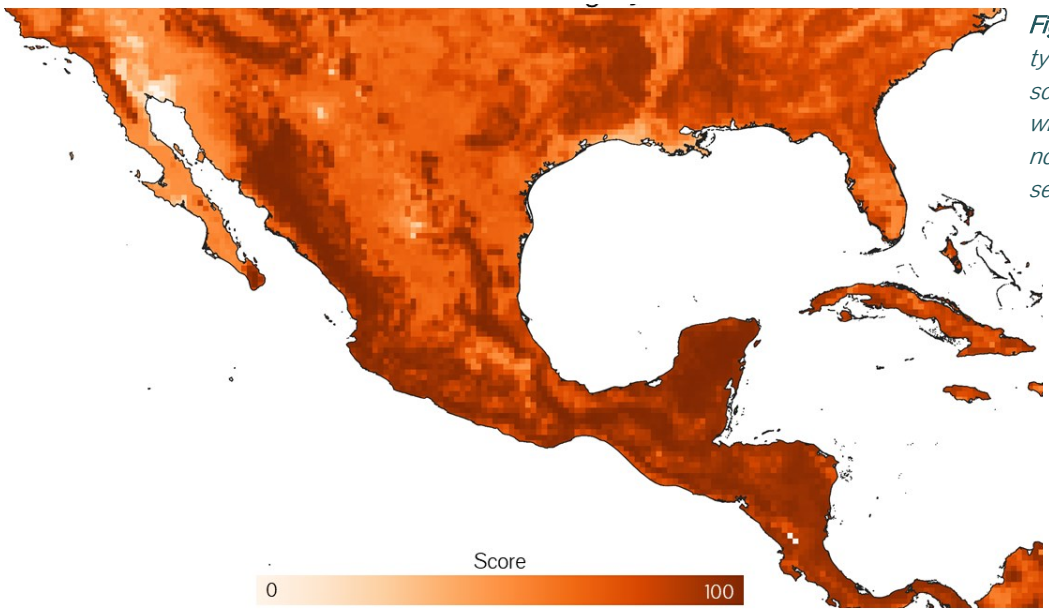


Figure 6. *Four Twenty Seven wildfire scores in Mexico, with 0 representing no risk and 100 representing high risk.*

[37]Schuur, T., "Permafrost and the Global Carbon Cycle," *National Oceanic and Atmospheric Administration,* November 22, 2019, https://arctic.noaa.gov/Report-Card/Report-Card-2019/ArtMID/7916/ArticleID/844/Permafrost-and-the-Global-Carbon-Cycle.
[38]Borunda, Alejandra, "What a 100-degree day in Siberia really means," *National Geographic,* June 23, 2020, https://www.nationalgeographic.com/science/2020/06/what-100-degree-day-siberia-means-climate-change/#close.
[39]Lewis, Sophie, "Wildfires in Siberia have burned down an area larger than Greece," *CBS News*, July 21, 2020, https://www.cbsnews.com/news/wildfires-sibera-russia-burned-area-larger-than-greece-heat-wave/.
[40]Rudnitsky, Jake, Kravchenko, Stepan, Warren, Hayley, Pogkas, Demetrios, "The World's Largest Forest Has Been on Fire for Months," *Bloomberg*, August 8, 2019, https://www.bloomberg.com/graphics/2019-siberia-russia-wildfires/.
[41]Parfitt, Tom, "Vladimir Putin bans grain exports as drought and wildfires ravage crops," *The Guardian*, August 5, 2010, https://www.theguardian.com/world/2010/aug/05/vladimir-putin-ban-grain-exports.

The KBDI in the State of Mexico will reach upwards of 600/800 in areas surrounding Mexico City in our timeframe of analysis. This region already experiences wildfires today that affect air quality in the city, such as those in 2019 that led the government to urge citizens to stay indoors, close schools, and curb public works projects.[42] Mexico City, located in a valley where airflow can become stagnant, has historically struggled with air quality and pollution from heavy vehicle traffic and nearby industrial activity. The metropolitan area and surrounding rural areas will experience around 30 additional high potential wildfire days per year by 2030-2040, further threatening public health and productivity. Manufacturing facilities in this region are critical to global supply chains in industries like automobiles, pharmaceuticals, consumer goods, electronics, and aerospace. Major multinational brands including Volvo, Honda, Procter and Gamble, Novartis, and Viacom have facilities in this region, making them vulnerable to disruptions due to production restrictions during wildfire smoke events, which could lead to rippling impacts globally.

Western United States

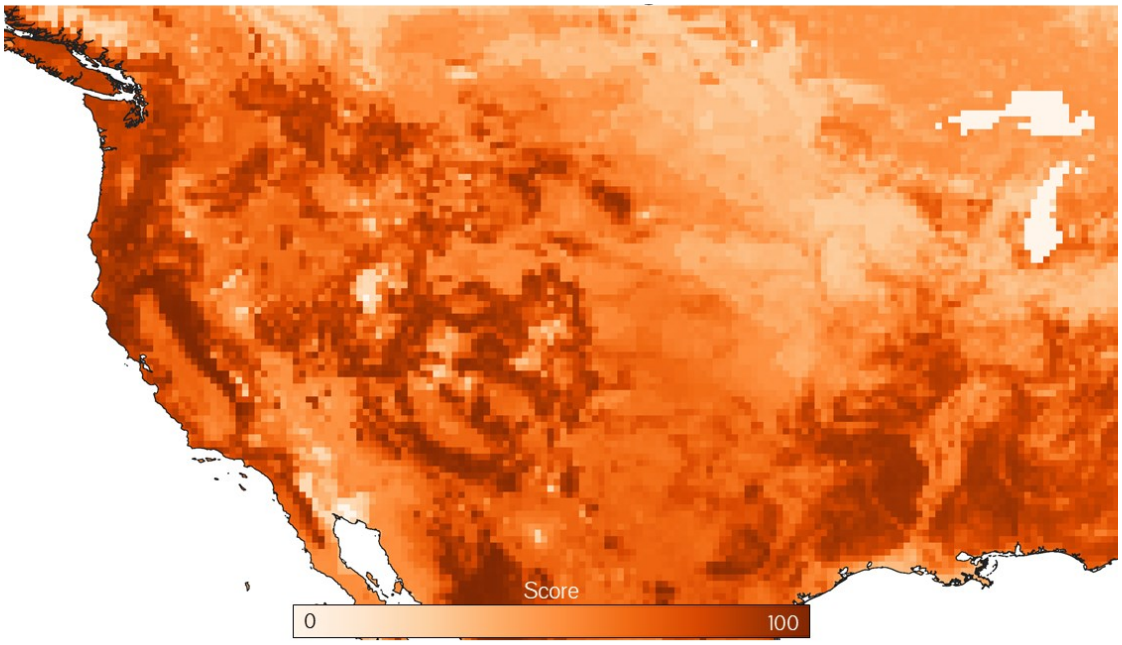


Figure 7. Four Twenty Seven wildfire scores in the western United States, with 0 representing no risk and 100 representing high risk.

The western United States has already experienced major impacts in recent years from heightened wildfire potential and lengthening wildfire seasons. Fires in this region are increasingly frequent and larger than in the past, with many areas experiencing repeated wildfire events.[43] Areas north of San Francisco and eastward toward the foothills of the Sierra Nevada mountains have particularly high wildfire scores due to drying patterns and abundance of vegetative fuels, with an additional two months of high

[42]Sherida, Mary Beth, "The scary images of Mexico City's pollution emergency," *The Washington Post,* May 16, 2019, https://www.washingtonpost.com/world/2019/05/16/scary-images-mexico-citys-pollution-emergency/.
[43]Patel, Kasha, "Six trends to know about fire season in the western U.S.," *NASA*, December 5, 2018, https://climate.nasa.gov/blog/2830/six-trends-to-know-about-fire-season-in-the-western-us/.

wildfire potential days expected by 2030-2040. Meanwhile, areas south of the Yukon River in Alaska that endured large damaging fires in 2019,[44] will also become more wildfire-prone in the coming decades.

Firefighters and ecologists already report a trend towards prolonged wildfire seasons,[45] and Four Twenty Seven's analysis supports other climatological evidence[46,47] that high wildfire potential days in parts of the western United States could last for the majority of the year by the end of century. Northern California wildfires caused the first climate change bankruptcy, of Pacific Gas & Electric (PG&E).[48] The bankruptcy proceedings for PG&E will end with an outlay of $58 billion and incalculable damage to the company's reputation.[49] Meteorological conditions that were very conducive to wildfire, highly flammable forest overgrowth, and a downed power line in PG&E's service area caused one of the most destructive wildfires in the region's recent history, the 2018 Camp Fire.[50] The company pled guilty to 84 counts of felony involuntary manslaughter in the Camp Fire and the affected town of Paradise remained gutted a year later, with just 3,000 of the former 26,000 residents having returned home.[51] Because of continuing wildfires risks, PG&E scheduled blackouts which affected up to two million people in 2019, with severe impacts on local businesses, families and the most vulnerable, including those relying on life-preserving equipment. Planned blackouts can be expected to recur in the future as climate change-induced wildfire conditions persist.

PG&E's story is a symbol of the challenging questions around forest management, utility responsibility, insurance coverage, and development practices that increasingly dominate conversations in western states and will require more focus from decision-makers as wildfires seasons worsen and lengthen.[52] The risk is magnified by growth and development in the wildland-urban interface, where houses, buildings, and other infrastructure intersect with natural areas. The wildland-urban interface grew by 41% between 1990-2010 in the United States.[53]

In 2018, five other western states also broke local wildfire records.[54] Colorado saw nearly 3,000 fires that year, dry conditions led to large fires in Hawaii, and Oregon and Utah set records for fire suppression expenditures and loss of property, respectively. Hot and dry conditions combined with the build-up of flammable wildfire fuels will lead to larger fires and longer wildfire seasons across the western United States with implications for public health, insurance, local governments, and economies.

[44]Theriault Boots, Michelle, "Hess Creed fire, burning in Alaska's Interior, is largest wildfire in the nation," *Anchorage Daily News,* July 9, 2019, https://www.adn.com/alaska-news/2019/07/10/hess-creek-fire-burning-in-alaskas-interior-is-largest-wildfire-in-the-nation/.
[45]Matt Richtel and Fernanda Santos, "Wildfires, Once Confined to a Season, Burn Earlier and Longer," *The New York Times*, April 12, 2016, https://www.nytimes.com/2016/04/13/science/wildfires-season-global-warming.html.
[46]Mike D. Flannigan et al., "Implications of Changing Climate for Global Wildland Fire," *International Journal of Wildland Fire* 18, no. 5 (2009): p. 483, https://doi.org/10.1071/wf08187.
[47]A. Park Williams et al., "Observed Impacts of Anthropogenic Climate Change on Wildfire in California," *Earth's Future* 7, no. 8 (2019): pp. 892-910, https://doi.org/10.1029/2019ef001210.
[48]Gold, Russell, "PG&E: The First Climate-Change Bankruptcy, Probably Not the Last," *The Wall Street Journal,* January 18, 2019, https://www.wsj.com/articles/pg-e-wildfires-and-the-first-climate-change-bankruptcy-11547820006.
[49]Leidtke, Michael, "Judge to OK $58B Plan to End PG&E Bankruptcy After Wildfires," *KQED,* June 20, 2020, https://www.kqed.org/news/11825532/judge-to-ok-58b-plan-to-end-pge-bankruptcy-after-wildfires.
[50]"California utility PG&E pleads guilty to 84 wildfire deaths," *BBC*, June 16, 2020, https://www.bbc.com/news/world-us-canada-53072946.
[51]Siegler, Kirk, "The Camp Fire Destroyed 11,000 Homes. A Year Later Only 11 Have been Rebuilt," *NPR*, November 9, 2019, https://www.npr.org/2019/11/09/777801169/the-camp-fire-destroyed-11-000-homes-a-year-later-only-11-have-been-rebuilt.
[52]Ruiz, Sarah, "California Made Headlines, but 5 Other U.S. States Also Broke Wildfire Records in 2018," *World Resources Institute,* March 7, 2019, https://www.wri.org/blog/2019/03/california-made-headlines-5-other-us-states-also-broke-wildfire-records-2018.
[53]Radeloff, Volker C. et. al., "Rapid growth of the US wildland-urban interface raises wildfire risk," *Proceedings of the National Academy of Sciences*, 24, (2018), https://doi.org/10.1073/pnas.1718850115.
[54]Ruiz, Sara, "California Made Headlines, but 5 Other U.S. States Also Broke Wildfire Records in 2018," *World Resources Institute,* March 7, 2019, https://www.wri.org/blog/2019/03/california-made-headlines-5-other-us-states-also-broke-wildfire-records-2018.

TAKING ACTION

We have already experienced some of the financial implications of wildfires across the globe. Yet wildfires have significant, if not yet fully understood implications for public health, local governments and financial markets. The cost of wildfire suppression alone in the United States in 2018 reached $3 billion and is climbing.[55] Other expenses reach into the billions per year from loss and damage to buildings, infrastructure, and homes, and increased healthcare costs. Wildfire-affected areas can expect slowdowns in economic growth from diminished revenues for local businesses, reduced agricultural output, and declines in tourism, which all represent significant threats to the tax base. Sometimes those tax base reductions can become an existential threat to towns if homeowners choose not to rebuild, as may be happening to Paradise, California following the 2018 Camp Fire. As wildfires become more frequent and severe, impacts including total devastation of towns, mass migrations, and public health crises will present significant challenges for policymakers and investors. Investors have an opportunity to be ahead of the curve when it comes to understanding and preparing for these impacts and investing in widespread resilience.

Building resilience to wildfires requires action at many different levels, from the individual building or homeowner up to state and federal leaders. Individual asset owners can take measures to protect properties by constructing to fire-resistant standards and pruning nearby trees. However, individual actions are not enough, especially when populations are rising in the wildland-urban interface and wildfire-prone areas are expanding because of climate change. Municipalities and local governments can consider setting stricter building codes and changing zoning laws to keep citizens in wildfire-defensible areas and can make investments in firefighting resources or create partnerships with neighboring communities to share those resources. At the national government level, policy changes are needed to more sustainably manage forests, reducing wildfire fuel through methods like thinning overgrown forests.[56] Additional potential adaptation actions at the individual, community, state, and federal levels are described in Table 2 below.

It is important to consider that state and local programs to finance resilience are often underfunded and obtaining fire insurance in high risk areas has been increasingly problematic for a number of reasons. While a large determinant of whether towns are rebuilt following major fires is insurance coverage, certain types of coverage and backstops from state and federal disaster funds can create incentives to continue to build and rebuild in dangerous areas,[57] leading to moral hazards if building owners implement fewer protections at the site-level, believing they have full coverage through their policies.[58] Meanwhile, mounting losses in recent years have caused insurers to attempt to non-renew policies and exit markets entirely.[59] California has put some temporary protections for homeowners into place, but this is part of the larger conversation around if and how to rebuild in wildfire prone areas and who

[55]Goering, Laurie, "Burned by wildfire losses, insurance industry rethinks risks," *Reuters,* January 22, 2020, https://www.reuters.com/article/us-wildfire-insurance-climate-change-ana/burned-by-wildfire-losses-insurance-industry-rethinks-risks-idUSKBN1ZL2RA.
[56]"Forest Resilience Bond: Fighting Fire with Finance, A Roadmap for Collective Action," *Blue Forest Conservation and Encourage Capital,* 2017, https://static1.squarespace.com/static/556a1885e4b0bdc6f0794659/t/59c1157f80bd5e1cd855010e/1505826201656/FRB+2017+Roadmap+Report.pdf.
[57]Flavelle, Christopher, "Why Is California Rebuilding in Fire Country? Because You're Paying for It," *Bloomberg*, March 1, 2018, https://www.bloomberg.com/news/features/2018-03-01/why-is-california-rebuilding-in-fire-country-because-you-re-paying-for-it.
[58]Baylis, Patrick and Boomhower, Judson, "Moral Hazard, Wildfires and Economic Incidence of Natural Disasters," *National Bureau of Economic Research Working Paper,* no. 26550, (December 2019), https://www.nber.org/papers/w26550.
[59]Flavelle, Christopher, "As Wildfires Get Worse, Insurers Pull Back From Riskiest Areas," *The New York Times*, August 20, 2019, https://www.nytimes.com/2019/08/20/climate/fire-insurance-renewal.html.

pays the bill.[60]

Financing for fire adaptation can also be complex, particularly in areas not yet experienced at fighting or preventing wildfires. Some solutions include forest management collaboratives between groups like private timber companies, environmental groups, and government agencies who share the burden of managing and restoring forests to be more sustainable and wildfire-resilient, as is done in Oregon.[61] There is evidence that communities not historically susceptible to wildfires are more likely to invest in adaptive measures following an event, provided that they also have government capacity and investment in land use planning, but it is prudent to make preparations ahead of time, rather than wait to respond until afterwards.[62]

Table 2. *Wildfire adaptation actions, modified from various sources*[63,64]

Wildfire Adaptation Actions	
Building-level Adaptations	• Build with fire-resistant materials • Build defensible space to prevent wildfires from reaching structures • Understand exposure of the building and obtain appropriate wildfire insurance coverage • Work with neighbors and meet with local fire agencies to identify and manage vegetative fuel sources in the vicinity
Community and State Adaptations	• Implement zoning based on up-to-date wildfire hazard mapping • Develop or update a Community Wildfire Protection Plan (CWPP) • Determine common causes of wildfires in the vicinity of the community and set regulations • Set and enforce codes for fire-adaptive building • Build defensible space to prevent wildfires from reaching structures • Implement innovative wildfire insurance mechanisms like catastrophe bonds, parametric insurance, and risk pools • Create and clearly communicate homeowner and building-owner responsibilities for maintaining fire-safe structures • Create and clearly communicate community response plans for when wildfires occur • Build partnerships between municipalities and regions to share wildfire fighting and prevention resources • Build partnerships with local businesses, research institutions and other community organizations to increase regional understanding of local wildfire risk and its implications
Federal Adaptations	• Allocate funds to forest restoration activities for wildfire mitigation and prevention including thinning overgrown forests, controlling invasive species, habitat restoration, prescribed fires, and building fire breaks • Create forest management plans that allow for natural wildfires, needed to maintain the health of the ecosystem, to occur • Leverage public-private partnerships to share financial burden of wildfire adaptation and prevention activities • Implement innovative wildfire insurance mechanisms like catastrophe bonds, parametric insurance, and risk pools

[60]Flavelle, Christopher and Plumer, Brad, "California Bans Insurers From Dropping Policies Made Riskier by Climate Change," *The New York Times,* December 5, 2019, https://www.nytimes.com/2019/12/05/climate/california-fire-insurance-climate.html.
[61]Moore, Kim, "Wildfires prompt calls for more private management of public forestland," *Oregon Business*, September 19, 2017, https://www.oregonbusiness.com/article/farms-forests/item/17998-wildfires-prompt-calls-for-more-private-management-of-public-forestland.
[62]Mockrin, Miranda H., Hillary K. Fishler, and Susan I. Stewart. "Does Wildfire Open a Policy Window? Local Government and Community Adaptation After Fire in the United States." *Environmental Management* 62, no. 2 (2018): 210–28. https://doi.org/10.1007/s00267-018-1030-9.
[63]"Forest Resilience Bond: Fighting Fire with Finance, A Roadmap for Collective Action," *Blue Forest Conservation and Encourage Capital,* 2017, https://static1.squarespace.com/static/556a1885e4b0bdc6f0794659/t/59c1157f80bd5e1cd855010e/1505826201656/FRB+2017+Roadmap+Report.pdf.
[64]"California fires: Building resilience from the ashes," *Zurich,* December 2019, https://www.zurichna.com/-/media/project/zwp/zna/docs/kh/wildfire/california-wildfire-report.pdf?la=en&hash=AB77A5B3CFC40E2C50ADB7F728728001

CONCLUSION

Four Twenty Seven's new wildfire indicators will help investors as well as corporate and government leaders to better understand where the potential for wildfire is growing globally. While we do not attempt to predict individual wildfire events, the data highlights areas of the globe where the frequency and severity of wildfire conditions is anticipated to worsen and emerge. Investors and business leaders armed with Four Twenty Seven's analytics that find themselves with economic interests in wildfire-prone areas can make informed decisions about their investments and make proactive decisions to mitigate their risk. In regions where wildfires are already occurring, this data can help decision-makers better understand how their future exposure is evolving with the changing climate and plan accordingly to build resilience. In regions where wildfires are an unfamiliar hazard, forward thinking leaders can prepare to respond to this new risk. There is a history of sharing firefighting resources across borders in places like the United States, Europe, Canada, New Zealand, and Australia, taking advantage of incongruent wildfire seasons.[65] As the climate changes and increasing temperatures expose new areas to risk, there is an opportunity to share resources and knowledge not only on how to fight fires, but how to understand them, prevent them, and build resilience against them.

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Four Twenty Seven (427mt.com), an affiliate of Moody's, is a leading publisher and provider of data, market intelligence and analysis related to physical climate and environmental risks. We tackle physical risk head on with analytics that identify the exposure of any location in the world to climate change hazards such floods, heat stress, hurricanes & typhoons, sea level rise, water stress and wildfires, which pose an immediate threat to investment and loan portfolios.

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[65]Pannett, Rachel and Cheney, Michael, "Fires in Australia, California Strain Shared Firefighting Resources," *The Wall Street Journal*, January 2, 2020, https://www.wsj.com/articles/wave-of-blazes-strains-firefighting-network-from-australia-to-california-11577954905.

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