1 Overview: Key findings and recommendations

Recent extreme wildfire events have caused unprecedented damages and had impacts on human communities, economies and the environment. Climate change is a key driver behind the growing occurrence of extreme wildfires. Under projected warming, wildfire frequency and severity are set to increase, calling for a fundamental shift in wildfire management towards enhanced wildfire prevention. This chapter summarises the main findings of this report, outlining observed and projected patterns in extreme wildfire activity as well as the emerging policy solutions to address them. The recommendations aim to inform countries' policy progress towards building climate resilience to extreme wildfires.

1.1. An overview of wildfire risk and impacts across regions

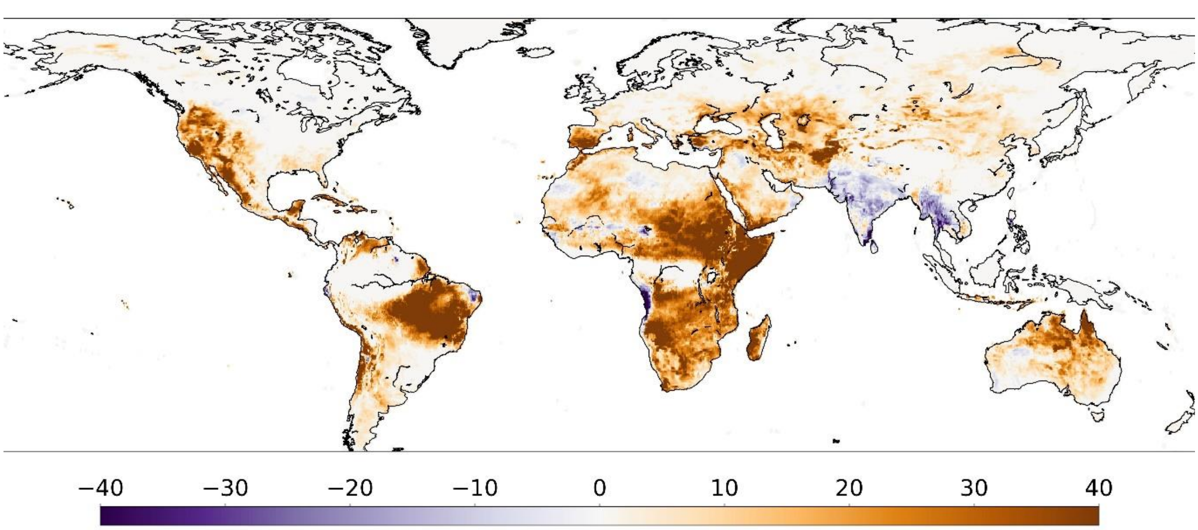
1.1.1. Extreme wildfires are a growing threat to humans, ecosystems and whole economies

Wildfire frequency, size and severity, as well as the duration of the fire season, are on the rise in many regions of the world. In Australia, average wildfire frequency almost doubled between 1980 and 2020, with an average annual increase in burned forest area of 350% between the early 1990s and 2018 (Canadell et al., 2021[1]). In the United States, wildfire severity (i.e. the degree of ecosystem impacts caused by a fire) increased eightfold between 1985 and 2017 across western forests (Parks and Abatzoglou, 2020[2]). The duration of the fire weather season, i.e. the annual period in which meteorological conditions are conducive to fire, grew by 27% globally between 1979 and 2019 (Jones et al., 2022[3]), with particularly large increases observed in southern Europe, western and central Asia, South America, western North America, Australia, and most of Africa (Jones et al., 2022[3]) (Figure 1.1).

The growing occurrence of extreme wildfires – i.e. wildfire events that are particularly severe in terms of their size, duration, intensity and impacts – can cause significant impacts on human lives and well-being, ecosystems and the climate system, as well as the economy. Extreme wildfire events have had particularly damaging impacts in recent years. The 2015 wildfires in Indonesia caused economic costs of about USD 16 billion, i.e. 2% of the national gross domestic product (GDP) (UNEP, 2022[4]). The 2018 Mati wildfires claimed over 100 lives in Greece (Kartsios et al., 2021[5]). The 2018 California Camp Fire produced an unprecedented USD 19 billion in economic damages, while in the following year, the 2019-20 wildfires in Australia burned 24-40 million hectares of land and caused an estimated USD 23 billion in economic damages (EM-DAT, 2023[6]; Royal Commission, 2020[7]).

Figure 1.1. Change in the duration of the fire weather season, 1979-2019

Change in the number of fire weather days



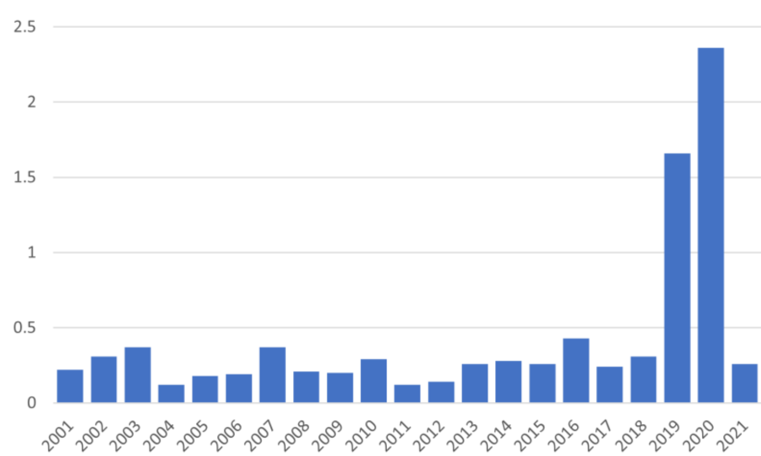
Notes: Cumulative change in the duration of the fire weather season between 1979 and 2019 based on data from Vitolo et al. (2020[8]) using the ERA5 dataset. Purple areas represent a decrease in the duration of the fire weather season, while brown areas represent an increase.
Source: Adapted from Jones et al. (2022[3]).

The human costs of wildfires go far beyond lives lost. Wildfires have long-term health impacts that can lead to respiratory and cardiovascular diseases and neurological disorders caused by wildfire-induced air pollution, as well as to psychological impacts (UNEP, 2022[4]). In the United States, smoke from wildfires is responsible for 25% of all harmful human exposure to $PM_{2.5}$ (fine particulate matter) and PM_{10} air pollution (USDA, 2022[9]). At the global level, the cardiovascular and respiratory impacts of wildfires are associated with 340 000 premature deaths every year (WWF, 2020[10]). The 2015 wildfires in Indonesia caused 100 000 additional deaths as well as acute respiratory infections for over 500 000 people (Uda, Hein and Atmoko, 2019[11]; Edwards et al., 2020[12]), which were associated with a direct health cost of USD 151 million (Glauber et al., 2016[13]). Wildfire-induced air pollution is projected to double by 2050 in several countries, including Canada, Mexico and the United States (Ford et al., 2018[14]). In addition, the traumatic experience of being caught in a wildfire, along with the displacement of populations and the loss of homes, livelihoods and personal belongings, can lead to major psychological trauma. For example, after the 2016 extreme Fort McMurray wildfire in Alberta, Canada, 60% of the evacuees experienced post-traumatic stress disorder (Belleville, Ouellet and Morin, 2019[15]).

Extreme wildfires can also have negative impacts on ecosystems. The 2019-20 wildfires in Australia caused the death or displacement of an estimated 3 billion animals, while almost 70 threatened species saw up to 50% of their habitat burned (Ward et al., 2020[16]; WWF, 2020[10]). Tree cover damage in the country was nine times higher in 2020 than in 2018 (WRI, 2021[17]) (Figure 1.2). Similarly, following the 2017 Chile wildfires, nearly 40% of critically endangered habitats suffered medium to high damage (van Hensbergen and Cedergren, 2020[18]). Freshwater ecosystems were also impacted during the 2019-20 Australia wildfires, with record fish mortality recorded in estuarine zones downstream of burned areas (Silva et al., 2020[19]). In some cases, increases in extreme wildfire events have also hampered ecosystem recovery after a wildfire. For example, in some areas of the United States, the area where pre-fire vegetation did not grow back to its initial state nearly doubled between 2000 and 2011 (Stevens-Rumann et al., 2018[20]). By affecting vegetation and soils, wildfires can also affect drinking water quality and increase water-related risks (UNEP, 2022[4]). For example, extreme wildfires can exacerbate drought and flood risk, as burned soils tend to absorb less water and increase run-off. While several studies have examined the short- and medium-term negative impacts of extreme wildfires on ecosystems, more systematic records of ecosystem damage and disruptions are needed to improve monitoring and inform wildfire risk reduction actions.

Figure 1.2. Trends of forest damage in Australia, 2001-21

Million hectares of forest area damaged



Note: The peak in forest damage observed in 2019 and 2020 is correlated with the exceptionally large area burned during the 2019-20 wildfire season. While tree cover damage may be permanent in some cases, tree cover damage is temporary in others.
Source: Based on WRI (2021[17]).

The economic costs of extreme wildfires are also significant. Between 2000 and 2017, wildfires are estimated to have caused EUR 3 billion of direct economic losses (e.g. lost and damaged assets, crops and livestock losses, etc.) every year in the European Union and USD 2.3 billion in the United States (Marsh & McLennan Companies, 2019[21]). Yet, direct costs only represent a share of higher costs to the economy and do not account for lost tax revenue, reduced property values, business interruptions, reduced productivity and recovery costs, among others. While these costs are often difficult to estimate, some studies suggest that total economic losses from wildfires in the United States could range from USD 63.5 billion to USD 285 billion every year (Thomas et al., 2017[22]). Between 2008 and 2012, the Amazon wildfires caused GDP losses of up to 1% in the state of Acre, Brazil (Campanharo et al., 2019[23]). While there is evidence for selected extreme wildfire events, there is no systematic record of past or future projected economic losses and damages from wildfires at the national or international level.

The wildland-urban interface (WUI), i.e. the area where the built environment and wildland vegetation meet, is where most socio-economic losses and damages from wildfires occur, as the exposure of people and assets is higher in these areas. In the western United States, the number of infrastructure assets destroyed by wildfires has increased by 246% over the past two decades (Higuera et al., 2023[24]). During the extreme 2018 Camp Fire in California, United States, over 18 800 buildings and infrastructure assets were destroyed (Karels, 2022[25]). In the United States, wildfires are estimated to cause a drop in property values of 10-20% on average up to 2 miles away from burned areas (WWF, 2020[10]). Certain economic sectors are particularly affected by wildfires. Between 2008 and 2018, wildfires were responsible for over USD 1 billion in losses in crop and livestock production globally (FAO, 2021[26]), while the 2017 wildfires in Canada alone resulted in the loss of a year's worth of timber production (Marsh & McLennan Companies, 2019[21]).

1.1.2. While wildfires are a natural part of ecosystem processes, extreme wildfires can cause abrupt and potentially irreversible disruptions

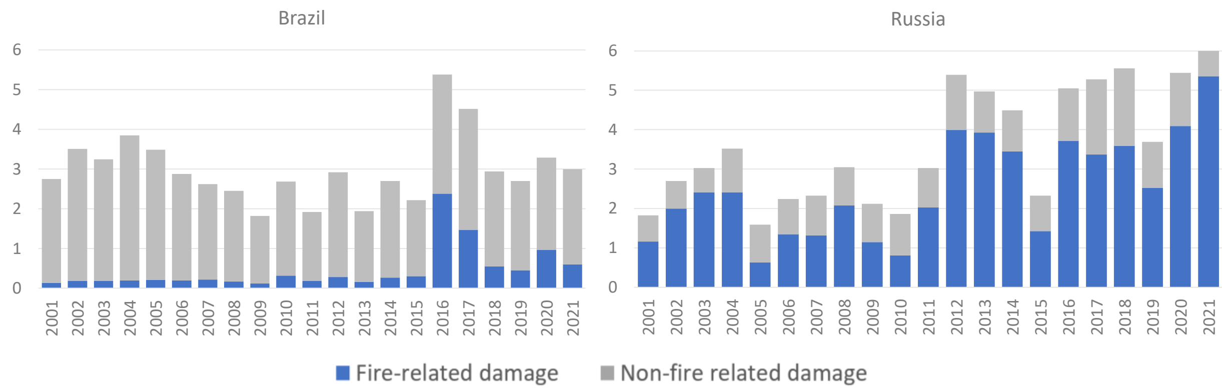
In many ecosystems, wildfires (i.e. unintended or uncontrolled fires that occur in wildland areas) are a natural component that provides important ecological functions. Species in these ecosystems may rely on regular fire activity to maintain their reproduction levels and growth (Hincks et al., 2013[27]). However, changing wildfire patterns pose growing challenges to the natural balance of ecosystems.

In ecosystems that are adapted to frequent or intense wildfires, such as boreal and Mediterranean forests, the growing occurrence of extreme wildfires has caused severe disruptions and hampered ecosystems' natural regeneration capacity (Turner et al., 2019[28]). In the Russian Federation (hereafter "Russia"), the extent of forestland affected by wildfires increased over fivefold between 2001 and 2021 (Figure 1.3).

Wildfires also increasingly occur where natural fire activity is rare, such as in tropical rainforests. In those areas, ecosystem resilience to fire is lower and the potential for irreversible damages is particularly high. For example, in 2016, wildfires affected more than 2.3 million hectares of forest area in Brazil (Figure 1.3) (WRI, 2021[29]). Intensive deforestation, combined with increased wildfire activity, has been associated with a large-scale, long-term tree cover loss in the Amazon region. This is pushing the Amazon rainforest towards a critical tipping point, which, if surpassed, might lead to abrupt and irreversible shifts in vegetation cover in the region, with impacts on global biodiversity and the global carbon cycles (Boulton, Lenton and Boers, 2022[30]; OECD, 2022[31]).

Figure 1.3. Annual forest area burned in Brazil and the Russian Federation, 2001-21

Million hectares of forest area burned



Note: While tree cover damage may be permanent in some cases, tree cover damage is temporary in others.
Source: Based on WRI (2021[29]) and WRI (2022[32]).

1.1.3. Important socio-economic drivers contribute to extreme wildfire occurrence and impacts

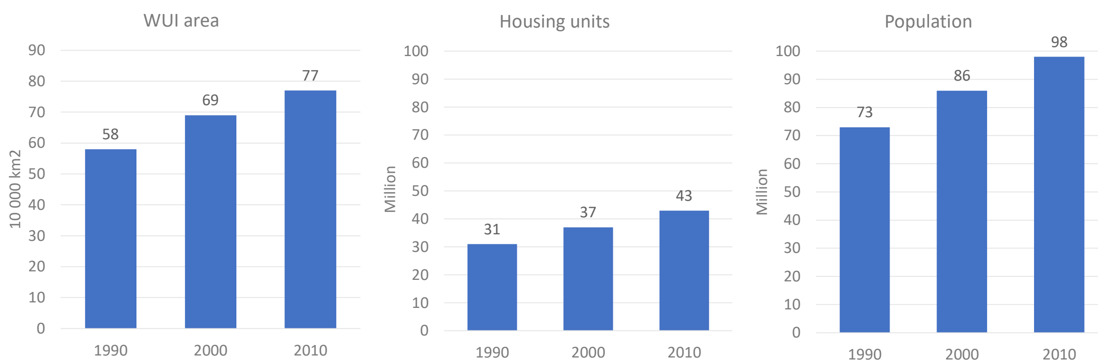
Human activity is the most common source of wildfire ignition and currently accounts for about 70% of the total land surface affected by fire globally (Veraverbeke et al., 2021[33]). The human ignition of wildfires can occur both accidentally (e.g. escaped campfires) or deliberately through arson. In France, Italy and Spain, over 95% of wildfires are caused by humans (WWF, 2019[34]). In the United States, it is estimated that over 80% of wildfires recorded between 2001 and 2009 were ignited by humans through accidents or arson (Hincks et al., 2013[27]). Utility failures, such as loose electricity cables or faulty power plants, were responsible for igniting 40% of the most destructive wildfires in California, including the devastating 2018 Camp Fire (LAO, 2021[35]). Similarly, downed power lines and arson were among the main ignition sources of the extreme 2009 Black Saturday wildfires in Australia (Parliament of Victoria, 2010[36]).

Human-induced ecosystem degradation is a key driver behind growing wildfire risk. The drainage of peatlands increases landscape flammability, as observed in Indonesia, where peatland degradation fuelled the extreme 2015 wildfires (UNEP, 2022[4]). Deforestation in Amazonia's and Indonesia's rainforests has also contributed to extreme wildfires, as permanent forest loss has worsened drought conditions and made ecosystems less resilient to wildfires (Nikonovas et al., 2020[37]; Pivello et al., 2021[38]). Certain agricultural and forestry practices, such as planting monocultures and non-native flammable species, also enhance wildfire risk, as shown during the wildfires in Chile in 2017, where non-native eucalyptus provided highly flammable fuel for wildfires over large areas (Barquín et al., 2022[39]).

Rural land abandonment and agricultural demise are other major socio-economic drivers of wildfire risk. Rural populations have played a key role in reducing fuel (i.e. vegetation) accumulation and continuity, including through agricultural practices (e.g. grazing and pruning trees in forests for firewood) and the creation of "mosaic" landscapes of agricultural crops that act as fuel breaks. With rural land abandonment, flammable vegetation encroaches and builds up. At the same time, rural land abandonment reduces the number of people available on the ground to detect and respond to wildfires early on (Moreira et al., 2020[40]). These trends are particularly marked in Mediterranean countries. For example, in Portugal, the rural population decreased from 5.7 million to 3.4 million between 1960 and 2021, i.e. from 65% to 33% of the total population (World Bank, n.d.[41]).

The growing WUI has increased the exposure of people and assets to wildfires, eventually increasing the impacts and losses suffered by communities and economic activities. Between 1990 and 2010, the WUI area in the United States increased by 33% while the WUI population increased by 34% (Figure 1.4), contributing to the devastating wildfire impacts observed in recent years (Radeloff et al., 2018[42]). In Greece, the substantial WUI growth around the city of Athens is likely to have contributed to the devastating impacts of the Attica wildfires in 2018 (OECD, forthcoming[43]).

Figure 1.4. Wildland-urban interface (WUI) area, population and number of housing units in the United States, 1990-2010



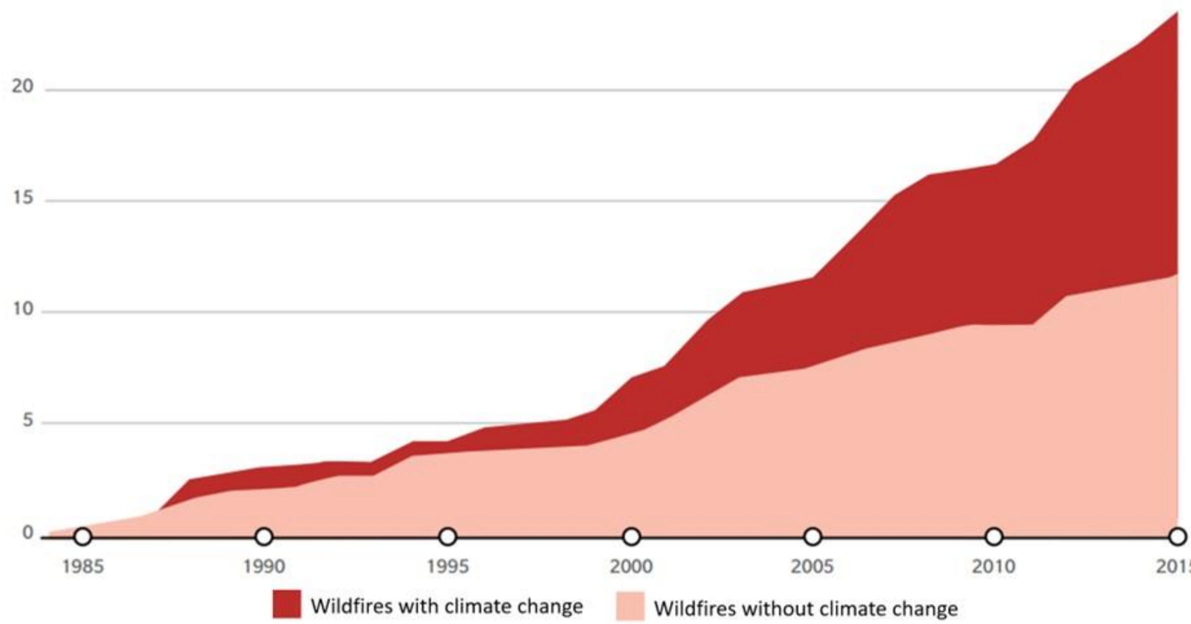
Notes: The WUI assessments were undertaken by Radeloff et al. (2018[42]) based on US Census data and the US Geologic Survey's NLCD.
Source: Based on Radeloff et al. (2018[42]).

There is mounting and conclusive evidence of the role of climate change in driving observed increases in wildfire extremes. Climate change influences the occurrence and patterns of wildfires by altering fire weather conditions. Higher atmospheric temperatures increase the occurrence of heatwaves and droughts, while earlier spring snowmelt can extend soil dryness for longer periods (Ellis et al., 2021[44]). In some regions, the reduced precipitation levels induced by climate change increase the dryness of the landscape, while climate change-induced alterations in wind and lightning patterns increase the likelihood of wildfire ignition and facilitate the spread of wildfires (UNEP, 2022[4]; IPCC, 2022[45]; Romps et al., 2014[46]). Besides, climate change also influences the characteristics and amount of fuel available to burn (Halofsky, Peterson and Harvey, 2020[47]). In some cases, increased precipitation during the vegetation-growing season can enhance the availability of fuel in the landscape, while the increased incidence of pests associated with higher temperatures and altered precipitation patterns can increase the amount of dead vegetation available to burn (Stephens et al., 2018[48]; Invasive Species Centre, 2022[49]).

The attributed climate change influence on observed wildfire extremes is stark. Climate change is estimated to have doubled the total forest area burned in the western United States between 1984 and 2015 (Overpeck, Dean and Stapp, 2018[50]) (Figure 1.5). The extreme fire weather that facilitated the 2019-20 wildfires in Australia was estimated to be at least 30% more likely because of climate change, while the extent of the 2017 extreme wildfires in Canada was 7 to 11 times higher because of climate change (van Oldenborgh et al., 2021[51]; Kirchmeier-Young et al., 2019[52]). A similar link has been established for the 2018 Camp Fire in the United States, where climate change is estimated to have doubled the likelihood of the extreme fire weather that facilitated the occurrence and spread of the blaze (Park Williams et al., 2019[53]; Goss et al., 2020[54]).

Figure 1.5. Cumulative forest area burned associated with climate change in the western United States, 1984-2015

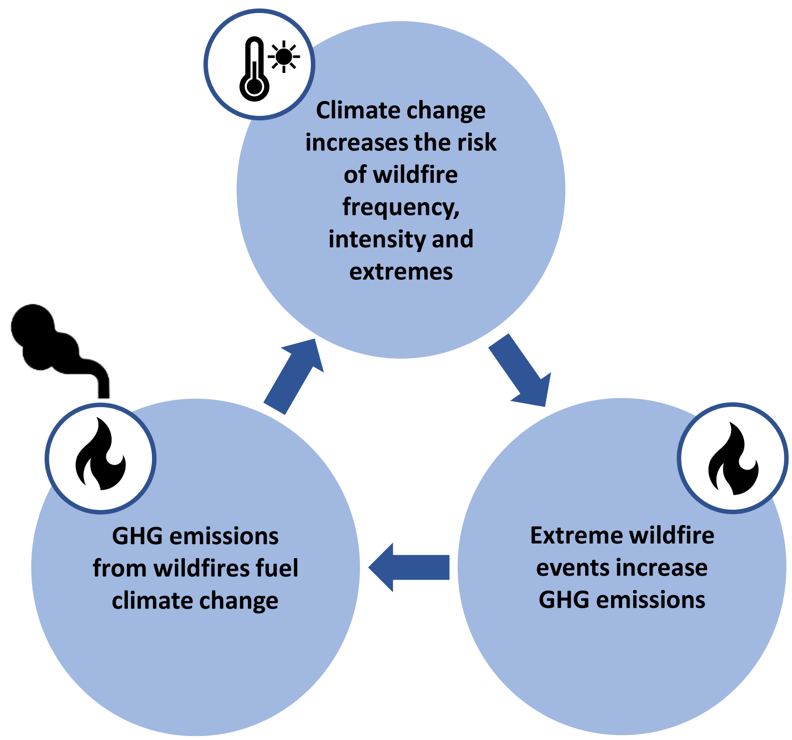
Million acres



Source: adapted from Marsh & McLennan Companies (2019[21]).

While human activities and climate change affect wildfires, wildfires, in turn, affect the climate system by releasing the carbon stored in vegetation and soil into the atmosphere (Figure 1.6). Under normal conditions, wildfires have a limited net influence on global carbon emissions, as wildfire emissions are mostly reabsorbed by regrowing vegetation in the aftermath of the fire (Jones et al., 2019[55]; Bowman et al., 2009[56]). However, with increasingly extreme wildfires, a net transfer of carbon dioxide (CO_2) from vegetation and the soil to the atmosphere has been observed (Friedlingstein et al., 2019[57]; Zheng et al., 2021[58]). For example, during the 2019-20 wildfires in Australia, CO_2 emissions were eight times higher than in the average wildfire season (van der Velde et al., 2021[59]). In 2020, the emissions from the California wildfires – which amounted to 127 million metric tonnes of CO_2 equivalent – were estimated to be twice as high as the total emission reductions achieved by the state as part of its climate change mitigation efforts between 2003 and 2019 (Jerrett, Jina and Marlier, 2022[60]). By burning vegetation and soil, extreme wildfires in forests and peatlands reduce land carbon storage capacity, further exacerbating this risk. Following the 1998 extreme wildfires in Russia, 2 million hectares of forestland lost their carbon storage capacity for at least a century (WWF, 2020[10]).

Figure 1.6. The feedback loop between climate change and extreme wildfires



Note: GHG: greenhouse gas.

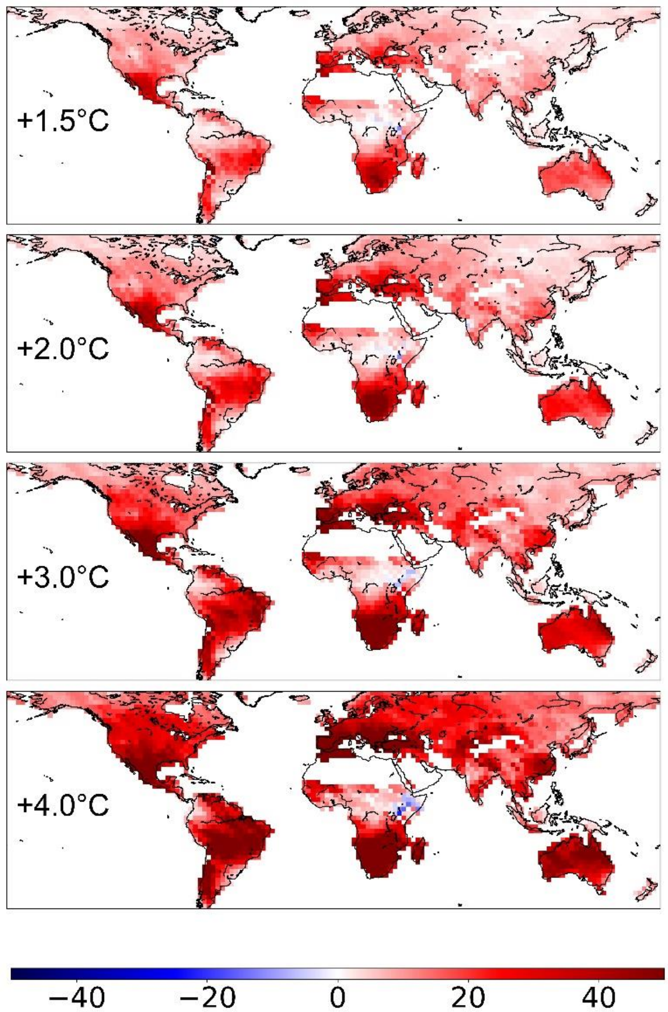
Source: Based on WRI (2022[32]).

1.1.4. Climate change is projected to further exacerbate future wildfire risk

Wildfire frequency and severity are set to rise in the future due to climate change (UNEP, 2022[61]). Under a 2°C warming scenario, many regions are projected to experience a large increase in wildfire frequency. Rising temperatures and drought conditions, coupled with changing precipitation and wind patterns, are also likely to extend the duration of the fire season (i.e. the period when weather conditions are conducive to the occurrence of wildfires) in most regions of the world, extending it by over 40 days per year in parts of the world under a high-warming scenario (Xu et al., 2020[62]; Bowman et al., 2020[63]; Jones et al., 2022[64]) (Figure 1.7). As a consequence, wildfire impacts are also likely to grow. Globally, area burned is projected to increase by 19% by 2050 (compared to 2000), under a moderate-emission scenario (RCP 4.5) (Zou et al., 2020[65]), while under a 4ºC warming scenario, wildfire frequency is projected to increase by 30% by the end of the century (IPCC, 2022[45]). By 2100, the yearly burned area in Greece's forests is projected to increase by up to 20% (compared to 2010 levels), leading to an annual direct cost of EUR 40 million to EUR 80 million by 2100 (Bank of Greece, 2011[66]). In Portugal, wildfire-induced losses in the tourism sector are projected to reach up to EUR 62 million annually by 2030, while by 2050, such losses are expected to at least quadruple (Otrachshenko and Nunes, 2022[67]).

Figure 1.7. Projected change in the duration of the fire weather season under climate change

Change in the number of fire weather days, compared to 1860-1920



Note: Projected changes are provided under different degrees of atmospheric warming (+1.5°C, +2.0°C, +3.0°C and +4.0°C) above pre-industrial levels.
Source: Adapted from Jones et al. (2022[64]) based on Jones et al. (2022[3]).

1.2. Adapting wildfire management to growing wildfire risk: State of play and policy recommendations

1.2.1. Changing wildfire risk calls for adapting wildfire management policies and practices

Countries need to adapt their wildfire management systems to limit future wildfire-induced losses and damages. Large and more frequent and intense wildfires will require significant suppression and emergency preparedness efforts, including fire monitoring and early warning systems. More importantly, wildfires need to be tackled at their source by scaling up preventative action. Fuel loads need to be better monitored and managed; ecosystems need to be protected from degradation; planted forest species need to be adapted to changing fire conditions; and wildfire risk assessments need to be better integrated into land-use decisions. Co-ordinated action and a strong enabling environment are required to enable changes to existing practices.

1.2.2. Countries have strengthened their emergency preparedness and response capacity

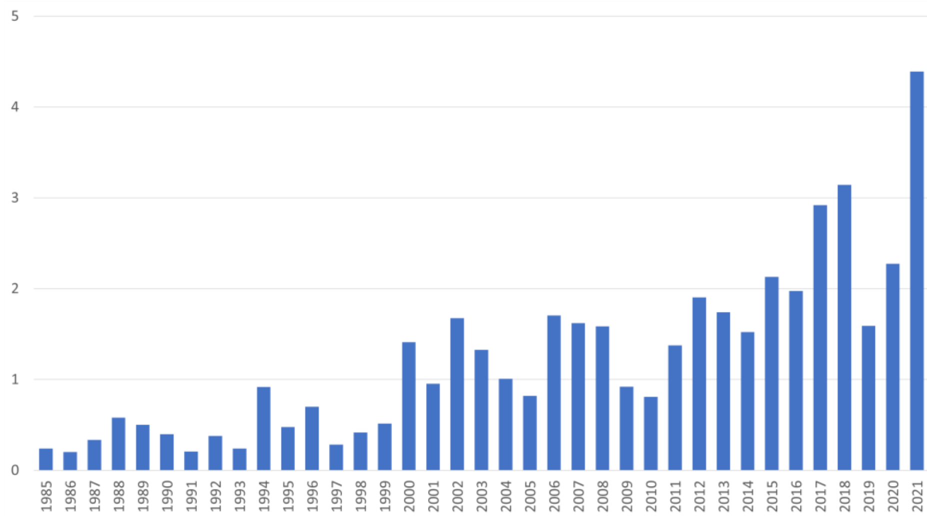
In reaction to extreme wildfires, some countries have significantly scaled up their emergency preparedness and response capacities, with a particular focus on strengthening wildfire suppression. Between 1998 and 2008, Greece doubled the public funding allocated for wildfire suppression, significantly scaling up aerial firefighting capacity (Xanthopoulos, 2008[68]), while the United States significantly increased federal funding for wildfire suppression (Figure 1.8), from an average USD 425 million per year in 1985-99 to USD 1.6 billion per year in 2000-19 (Roman, Verzoni and Sutherland, 2020[69]). Some countries have also enhanced cross-border co-operation mechanisms to support each other during emergency periods. For example, the European Union (EU)'s Civil Protection Mechanism, which co-ordinates disaster response across EU member and neighbouring countries, was further strengthened through the creation of rescEU operation, with a EUR 170 million funding envelope to enhance firefighting capacity across Europe (European Commission, 2022[70]). Several bilateral mutual support agreements also exist, e.g. between Canada and the United States (OECD, forthcoming[71]).

To better detect large wildfires, countries have also enhanced their wildfire risk monitoring capacities by strengthening their weather and fire monitoring systems. The European Forest Fire Information System (EFFIS) and EU Copernicus programme provide near-real time fire activity information (EFFIS, n.d.[72]; European Commission, n.d.[73]). The North American Space Agency (NASA) tracks soil moisture, provides vegetation maps, and monitors fire ignitions, active fires and post-fire recovery (NASA, n.d.[74]). These efforts are critical to detect potentially extreme fires early on and allocate resources accordingly.

Despite these significant efforts, increasing wildfire size, frequency and severity have highlighted the limits of emergency response measures (Xanthopoulos, 2008[68]; Parisien et al., 2020[75]; European Commission, 2021[76]) and the need to reduce the risk of extreme wildfires at the source (Ministry of the Environment and Energy, Greece, 2018[77]; Myers, 2006[78]). Extreme wildfire seasons have strained emergency response resources, limiting their ability to contain impacts. This challenge was observed, for example, during the extreme 2009 Black Saturday wildfires in Australia, which took over one month of firefighting efforts to be suppressed (Caohuu et al., 2015[79]). Similarly, during the 2017 wildfires in the Iberian Peninsula, the rate of fire spread exceeded the available firefighting capacity by three to nine times (WWF, 2020[10]). During the 2018 extreme wildfire season in Greece, the outbreak of multiple wildfires at the same time created a bottleneck in the deployment of firefighting resources, contributing to an unprecedented wildfire death toll in Mati, where over 100 people lost their lives (Xanthopoulos and Athanasiou, 2019[80]). In Alberta, British Columbia, and Ontario, Canada, wildfire suppression spending is projected to have to double by the 2071-2100 period to keep the current levels of fire response success (Hope et al., 2016[81]).

Figure 1.8. Increase in wildfire suppression costs in the United States, 1985-2021

Billion USD



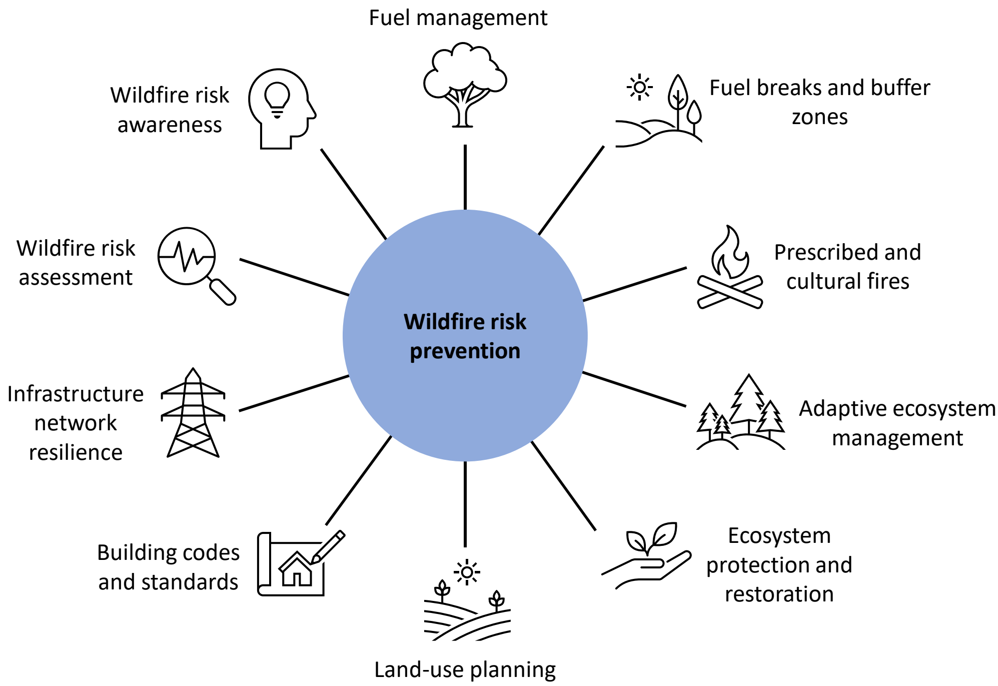
Note: The chart represents federal costs, including those incurred by the US Fire Service and the Department of the Interior's agencies.
Source: Based on data from the National Interagency Fire Center (n.d.[82]).

1.2.3. Reducing the risk of extreme wildfires relies on scaling up risk prevention measures

In the context of growing extreme wildfire risk, scaling up climate change adaptation measures as part of wildfire risk reduction efforts is critical. Only preventative action can effectively reduce wildfire hazard and exposure and vulnerability to wildfire impacts, while of course climate mitigation actions remain critical to addressing the climate driver at its source.

Wildfire prevention can take several forms (Figure 1.9), including organisational as well as structural measures. Organisational measures include wildfire hazard and risk assessment, awareness raising, as well as legislative and regulatory measures. Structural or "physical" measures include ecosystem-based interventions such as ecosystem protection, restoration and adaptive management, as well as fuel management interventions, including the creation of fuel breaks and buffer zones and the use of prescribed fires. Appropriate institutional, policy and financial arrangements are necessary to enable investments in risk prevention measures.

Figure 1.9. Reducing the risk of extreme wildfires through prevention measures



1.2.4. The protection, restoration and adaptative management of ecosystems reduce the occurrence and impacts of wildfires

Healthy ecosystems are more resilient and less prone to negative wildfire impacts. Climate change, combined with ecosystem degradation, has led to more fire-prone conditions in many regions. Following extreme wildfire events, the protection and restoration of degraded forests and peatlands has become a key element in many countries' wildfire risk prevention efforts. Forest restoration efforts – which can entail interventions such as reforestation, tree diversity restoration, and the control of invasive and underbrush species (i.e. species growing underneath the tree canopy) (Tobin-de la Puente and Mitchell, 2021[83]) – are at the centre of wildfire risk prevention efforts in Costa Rica, Gambia and South Africa (UNEP, 2021[84]; Republic of South Africa, 2022[85]). The United States has recently issued an executive order to protect old-grown forests with a view to reducing wildfire risk (The White House, 2022[86]).

Similarly, in the aftermath of the 2015 extreme wildfires, Indonesia extended the moratorium on issuing new permits for the development on primary forests and peatlands (Wijaya et al., 2016[87]) and established an agency dedicated to peatland restoration (Ward et al., 2021[88]; Wijaya et al., 2016[87]). Yet, further efforts are needed to effectively protect and restore wildland ecosystems from illegal activity and unsustainable land-use changes, as well as to scale up monitoring and enforcement efforts. In some cases, unclear or unknown forest ownership also limits the effectiveness of these measures (The Nature Conservancy and Aspen Institute, 2023[89]).

In light of climate change, some countries have also scaled up their efforts to ensure the adaptive management of forests to reduce landscape flammability. Managing forests in an adaptive manner can include, for example, planting fire-resilient species and excluding particularly fire-prone species in high-risk areas to adapt vegetation cover to growing wildfire and drought risk (Fitzgerald and Bennett, 2013[90]). These interventions are particularly important given the increasing prevalence of highly flammable non-native species in some countries. For example, in mainland Portugal, the extent of eucalyptus forests – which are highly flammable – grew by 62% between 1990 and 2017 (APA, 2020[91]). To address this challenge, the country developed a financial scheme promoting the plantation of native species on private lands to reduce landscape flammability (OECD, forthcoming[92]). However, scaling up and monitoring such adaptive forest management is key, especially in the context of climate change.

1.2.5. There is growing recognition of the importance of fuel management

Managing fuel accumulation in the wildland-urban interface is critical for reducing wildfire risk and impacts, as it reduces the amount of vegetation available to burn, especially in the vicinity of exposed settlements or assets. Fuel accumulation is usually managed through the use of prescribed fires (i.e. controlled fires to reduce fuel accumulation) and mechanical fuel removal or grazing to create buffer zones (i.e. strips of non-flammable land near settlements) and fuel breaks (i.e. patches of non-flammable land that reduce fuel continuity).

Prescribed fires are a relatively common tool to manage fuel accumulation and wildfire risk. While some countries, such as Australia and the United States, largely rely on prescribed fires to reduce fuel accumulation (Burrows and McCaw, 2013[93]; Melvin, 2021[94]), their use is limited in several European countries. France and Portugal have only recently set up specific legal frameworks to regulate and enable the safe use of fire (Montiel and Kraus, 2010[95]). The traditional use of fire in agricultural and land-use practices has led Australia, the United States and the Bolivarian Republic of Venezuela to engage with indigenous and local communities to integrate the active use of fire in wildfire prevention plans (Pardo Ibarra, 2020[96]; OECD, 2021[97]). In Australia, the enhanced use of cultural fires, i.e. fires ignited by indigenous groups and local communities to manage the land, was associated with a 50% reduction in area burned between 2000-06 and 2013-19 (OECD, forthcoming[98]). Despite the good practices described above, the high-risk perception associated with prescribed and cultural fires, together with limited awareness of their benefits, hampers their effective use in many countries (Müller, Vilà-Vilardell and Vacik, 2020[99]; Montiel and Kraus, 2010[95]).

Fuel breaks and buffer zones are more commonly used fire risk prevention measures. In Australia and Portugal, extended fuel breaks systems that strategically alternate different land cover types have effectively reduced landscape flammability (OECD, forthcoming[98]; forthcoming[92]), while after the extreme 2018 Camp Fire, the municipality of Paradise (California) bought some of the private lands most affected by the blaze to turn them into non-flammable fuel breaks (Brasuell, 2021[100]). Following particularly extreme wildfire events, both Greece and Portugal also mandated the creation and maintenance of buffer strips in high-risk areas. In Portugal, these are mandatory for both new and existing buildings in WUI areas; in Greece, tenants and owners in high-risk areas are required to remove excess vegetation and other flammable materials from the perimeter surrounding their assets before the start of the wildfire season (OECD, forthcoming[92]; forthcoming[43]). Yet, local governments face limited monitoring and enforcement capacities, thus reducing the full potential of fuel break measures (Moreira et al., 2020[40]; OECD, forthcoming[92]).

Acknowledging the importance of private stakeholder engagement in fuel management, many countries have also increased awareness-raising efforts to promote a better understanding of existing risk levels and have developed incentives to encourage active land management in private lands. In the United States, tax credits and deductions are available for farmers and landowners to encourage active fuel management on private lands (Kunreuther and St. Peter, 2020[101]). In Mediterranean countries such as France, Israel, Portugal and Spain, incentives to shepherds to encourage grazing activities on fuel-rich land have proven a winning strategy to contain fuel accumulation (Komac et al., 2020[102]). Portugal's Condomínio de Aldeia programme promotes active land management through community engagement (OECD, forthcoming[92]). However, low monitoring and enforcement, together with the lack of official land registries and unclear forest ownership, can limit the effectiveness of these measures (The Nature Conservancy and Aspen Institute, 2023[89]). This is the case, for example, in Portugal, where over 20% of forestlands have no or unknown owner and only 46% of forest areas are covered by the land registry. To address these issues, Portugal has recently released a new law which enables the state to carry out fuel management activities in areas of unknown ownership or where the owner fails to carry out the requested management efforts (OECD, forthcoming[92]).

1.2.6. Land-use planning and building regulations are critical to protecting lives, livelihoods and socio-economic assets

Land-use planning is critical to limit the exposure of human lives and assets to wildfire risk. Most notably, land-use zoning can limit urban sprawl in the wildland-urban interface (see Section 1.1.3). To inform this, wildfire hazard models need to be integrated into land-use planning processes. In recent years, countries have used land-use zoning to reduce wildfire exposure. For example, in France and Portugal, the construction of new buildings is generally forbidden in zones characterised as “high” or “very high” wildfire risk (OECD, forthcoming[92]; Presidency of the Council of Ministers, Portugal, 2021[103]; Kocher et al., 2017[104]). In France, housing development in “moderate” wildfire risk areas is allowed when specific risk reduction measures are adopted, such as the use of non-flammable building materials (Kocher et al., 2017[104]). On the other hand, in Greece, unclear zoning and high demand for development in the WUI, combined with an outdated hazard map, has contributed to housing expansion in fire-prone areas (Triantis, 2022[105]; Blandford, 2019[106]). During the Mati wildfire in 2018, the high number of assets that did not have a building permit contributed to the severe wildfire impacts, resulting in a building destruction rate of 80% (Hellenic Republic, 2021[107]; Blandford, 2019[106]; OECD, forthcoming[43]).

Building codes and standards also play a key role in minimising the impacts of wildfires once these occur. Buildings constructed with non-flammable materials and incorporating fire protections such as metal screens and spark arresters can reduce wildfire impacts fivefold compared to highly flammable structures (Czajkowski et al., 2020[108]). Countries have developed stricter standards for building design and maintenance in high-risk areas. For example, Greece and Portugal mandate the use of non-flammable materials and structural protection measures for new buildings and set out requirements on retrofitting existing ones in high-risk areas (OECD, forthcoming[92]; forthcoming[43]; Hellenic Republic, 2021[107]). In an effort to strengthen building code compliance, some communities in the United States have started to issue fines (Roman, 2018[109]).

1.2.7. Infrastructure design, operation and management contribute to wildfire resilience

As wildfire risk grows, strengthening infrastructure resilience is critical. This includes effectively planning and managing infrastructure to reduce the risk of wildfire ignition, as well as designing infrastructure assets and networks that are themselves resilient to wildfire risk by ensuring the continuity of their services and operations even in the occurrence of a wildfire event. The level to which critical infrastructure systems are resilient to wildfire risk contributes to society's resilience as a whole (IPCC, 2022[110]). Countries have developed regulations to require infrastructure operators to abide by fire safety rules and develop contingency plans. For example, Canada requires its two largest train companies to reduce train speed during high wildfire risk periods, as well as to remove flammable materials from the tracks (Scherer, 2021[111]). Following the extreme 2009 Black Saturday wildfires, the state of Victoria, Australia, established an AUD 750 million Powerline Bushfire Safety Program, which – by upgrading the electricity distribution network and regulating infrastructure management – was successful in reducing wildfire risk from powerline ignition (OECD, forthcoming[98]; Victoria State Government, 2022[112]). In Portugal, the Climate Change Adaptation Action Plan sets the ambition to have 50% of its transport infrastructure companies develop an adaptation or contingency plan for extreme events by 2030 (Government of Portugal, 2019[113]). Yet, in many cases, government regulations lag behind in this field, with wildfire prevention measures often being implemented by infrastructure operators on a voluntary basis.

1.2.8. Better wildfire risk assessments are needed to inform the changing needs for wildfire risk prevention

Information on wildfire hazard and wildfire risk is the basis for all wildfire risk prevention and preparedness decisions. Countries are increasingly aware of changing wildfire patterns and the need to better account for the links between climate change and extreme wildfire risk. An increasing amount of geospatial data has become available, allowing to better understand, model and map wildfire hazard, drivers and behaviour over time. Based on these data, many countries have developed hazard maps that are used to inform wildfire policy interventions throughout the territory. For example, Portugal and the United States have national wildfire hazard maps that classify the territory by hazard level (USDA, n.a.[114]; DGT, n.a.[115]). In Portugal, each municipality is also required to have a wildfire hazard map, which must be updated every ten years (OECD, forthcoming[92]; forthcoming[71]). However, hazard assessment alone is not sufficient to provide a comprehensive assessment of wildfire risk. As exposure and vulnerability are key drivers of risk, wildfire hazard assessments need to be integrated with spatial information on the exposure and vulnerability of human and ecological assets and systems. Yet, in most cases, integrating socio-economic information into wildfire risk assessments remains a challenge. While the United States has started to develop wildfire risk maps, which integrate hazard data with information on human and asset exposure and vulnerability (OECD, forthcoming[71]; Jacome Felix Oom et al., 2022[116]), these are not yet developed systematically by most countries. Persisting data gaps limit the availability of hazard and risk maps at different spatial scales and challenge their regular update. Limitations in wildfire models' predictive capacity limit the accuracy of existing projections. Besides, even where projections on future wildfire activity do exist, they are often not integrated into risk assessment and planning processes. Overall, countries struggle to integrate and keep abreast of growing scientific knowledge on the complex links between climate change and extreme wildfire hazard.

1.2.9. A cross-governmental effort is needed to reduce wildfire risk

The drivers of wildfire risk, as well as some of the key tools available to manage those risks, link to the roles and responsibilities of several stakeholders. For this reason, wildfire risk prevention needs to be integrated into the work of many sectors and all levels of government. Forest and land managers, critical infrastructure operators, spatial planning agencies, meteorological services, agriculture ministries, civil protection agencies, local governments, and private property owners all have a critical contribution to make in preventing wildfires. Countries are seeking to leverage this whole-of-government approach in different ways. Australia, Portugal and the United States have developed national wildfire management strategies that provide an overarching policy framework guiding the work of all relevant agencies. For example, Portugal's National Plan for Integrated Rural Fire Management establishes national policy objectives on wildfire management (OECD, forthcoming[92]). The first mid-term review in 2025 will show how well this ambitious plan has helped foster prevention across government agencies (OECD, forthcoming[92]).

To further reinforce the whole-of-government effort for preventing wildfires, some countries have also created dedicated co-ordinating agencies. In response to the 2017 wildfires, Portugal established the Agency for the Integrated Management of Rural Fires (AGIF), a cross-governmental body under the authority of the Prime Minister that promotes collaboration, fosters knowledge exchange and co-ordinates actions by relevant agencies and stakeholders through cross-governmental committees (OECD, forthcoming[92]). In only a few years, AGIF succeeded in bringing wildfire prevention to the centre of wildfire management efforts in the country. In 2022, Greece created a joint ministry for civil protection and climate change adaptation in an effort to strengthen prevention investments for climate-related risks, including wildfires (OECD, forthcoming[43]).

The degree to which wildfire risk reduction efforts are integrated across all relevant government agencies can be seen in the mainstreaming of prevention considerations into sectoral policies. For example, in Greece, the National Forest Strategy sets out objectives for wildfire prevention by identifying priority areas for action, developing forest maps, informing wildfire management interventions and preparing forest fire prevention plans (OECD, forthcoming[43]; Ministry of the Environment and Energy, Greece, 2018[77]). Similarly, in Portugal, the National Forest Strategy and its subordinate regional forest management programmes encourage the active management of forested lands, while the National Programme for Spatial Planning Policy identifies the rural areas most exposed to wildfire risk and outlines key adaptation actions (OECD, forthcoming[92]; APA, 2020[91]; Council of Ministers, Portugal, 2015[117]; Government of Portugal, 2021[118]).

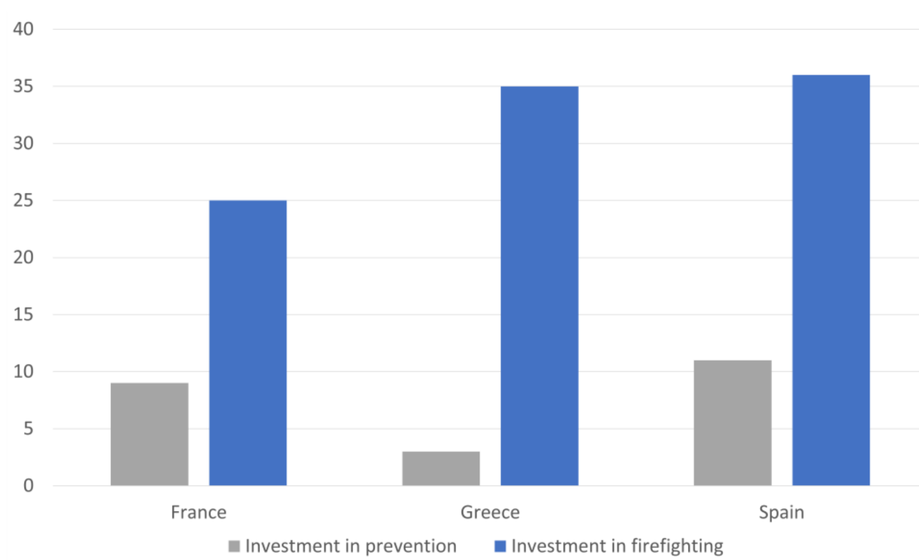
Despite these promising efforts, wildfire management remains fragmented in many countries. Evidence from Greece and Portugal shows that the limited collaboration and co-ordination across governments, key agencies and sectors has limited the effectiveness of wildfire management (OECD, forthcoming[43]; forthcoming[92]). For example, until recent improvements, collaboration has been low between agencies responsible for wildfire prevention and suppression actors in Greece (GFMC, 2019[119]). The investigations carried out after the 2017 extreme wildfires in Portugal also found that the unclear distribution of roles and responsibilities has led to institutional overlaps or gaps, contributing to the high wildfire impacts (Council of Ministers, Portugal, 2020[120]; OECD, forthcoming[92]). Overall, the effective integration of wildfire prevention into sectoral policies remains the exception rather than the norm.

1.2.10. Wildfire risk prevention needs appropriate funding

While strong recognition of the need to invest in wildfire risk prevention can be observed across countries, the increase of available funding to date has mostly benefitted emergency preparedness and response capacities. Wildfire suppression spending in many wildfire-prone countries is still up to six times higher than the recorded risk prevention spending (Figure 1.10). In Greece, the funding allocated to the Forest Service – the main entity responsible for wildfire prevention – shrank by nearly 30% between 2010 and 2017, from EUR 116 million to EUR 83 million (GFMC, 2019[121]; OECD, forthcoming[43]). In many countries, funds initially earmarked for wildfire prevention get diverted to fund emergency response, further exacerbating prevention funding gaps (North et al., 2015[122]).

Figure 1.10. Public investments in prevention and suppression in France, Greece and Spain

EUR per forest hectare

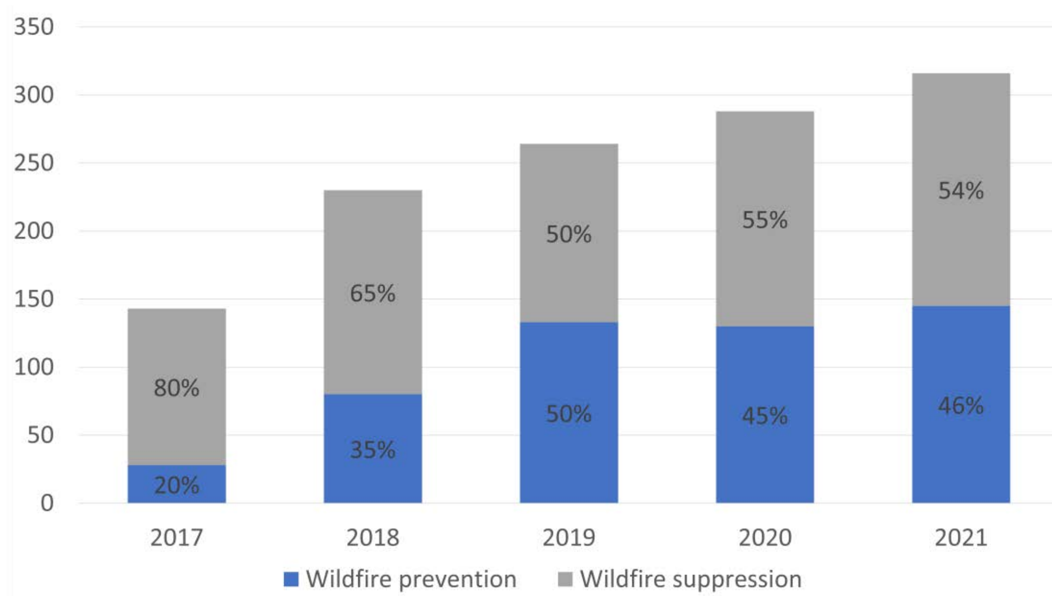


Notes: Information on Spain is based on data from the Spanish Official School of Forestry Engineers and refers to the period 2008-17. It includes state and regional investment, as regional governments share competences in forest management. Information on France is based on data from the National Institute of Geographic and Forest Information and refers to the period 2009-18. Information on Greece is based on WWF estimations.
Source: Based on WWF (2019[34]).

In some countries, extreme wildfires in recent years have triggered a shift in resource allocation. In response to the extreme 2017 wildfires, Portugal significantly boosted the public budget available for wildfire prevention (AGIF, 2021[123]), bringing prevention and suppression funding to near parity (Figure 1.11). While in 2017 only 20% of wildfire management funding was allocated to prevention, by 2021 wildfire prevention received 46% of all public wildfire funds, reaching EUR 145 million (OECD, forthcoming[92]; AGIF, 2021[123]). Funding for wildfire prevention also increased in Greece in 2022, thanks to support from the EU Recovery and Resilience Facility, in addition to national funding efforts. As a result, EUR 72 million were allocated for the AntiNero wildfire prevention programme (Ministry of the Environment and Energy, Greece, 2022[124]; OECD, forthcoming[43]).

Figure 1.11. The shifting focus from suppression to prevention in national public funding in Portugal, 2017-21

Million EUR



Source: Based on AGIF (2021[123]).

Insurance coverage for wildfire risk can also play a key role in scaling up wildfire prevention by identifying areas at risk and incentivising private investments in risk reduction measures. Insurance premiums can be made to reflect the level of exposure and vulnerability of insured assets. For example, lower insurance premiums can be offered to policy holders whose assets are in line with wildfire building standards. In the United States, some insurance companies give a 5% discount on insurance premiums to homeowners that undertake certain wildfire prevention measures (Galbraith, 2017[125]). In California, the “Safer from Wildfires” programme legally mandates insurance providers to reward wildfire prevention efforts undertaken by insured individuals by reflecting these in risk scores and giving corresponding discounts on insurance premiums (California Department of Insurance, n.d.[126]). In the absence of insurance coverage for wildfire risk, governments often step in to compensate for privately incurred losses and damages. Catastrophe risk insurance programmes, such as France’s CatNat system, can be a way to keep insurance premiums affordable while backing up insurance providers through a state guarantee in case of an extreme event (OECD/The World Bank, 2019[127]).

Yet, despite some efforts, countries struggle to secure sufficient insurance availability, affordability and coverage in risk-prone areas. In high-risk areas, access to insurance is rendered ever more difficult by the growing occurrence of extreme wildfires. For example, after the 2018 wildfires in California, insurance premiums rose by up to 500% in some areas. Insurance providers also refused to renew their coverage after the devastating Camp Fire, leaving 340 000 policy holders uninsured (Moss and Burkett, 2020[128]). Even when insurance is available, uptake rates remain low. For example, only 9% of all wildfire losses in Greece were covered by insurance between 1990 and 2019 (OECD, 2021[129]).

Box 1.1. Recommendations: Adapting to a changing climate in the management of wildfires

Strengthen ecosystem protection and adaptive management for wildfire prevention

- Protect wildland ecosystems from degradation, illegal activity and land-use change through strict regulations, monitoring and enforcement.
- Restore degraded ecosystems to reduce their proneness to wildfire risk and secure the continued provision of their ecosystem services.
- Manage forests to adapt their structure and composition to changing wildfire risk in line with local needs and conditions.

Scale up fuel management efforts to reduce fuel accumulation and continuity

- Mandate the use and maintenance of buffer zones to protect assets in wildlife-urban interface (WUI) areas and ensure enforcement through regular monitoring and penalties for non-compliance.
- Develop fuel break systems and landscape mosaic areas to reduce landscape flammability, most notably near WUI areas.
- Enable the active use of fire for fuel management, agricultural and other purposes, establishing safe conditions and monitoring systems for its use.

Strengthen land-use planning and building regulations for wildfire prevention

- Regulate development in fire-prone areas via zoning regulations, restricting development in high-risk areas.
- Develop building codes and standards that mandate fireproof building design for new and existing buildings.
- Regulate infrastructure planning, design and operations to reduce wildfire risk, including by promoting resilient design, regular monitoring and maintenance, or network reconfiguration where needed.
- Ensure compliance with land-use planning and building regulations via awareness raising, economic incentives, and stricter monitoring and enforcement.

Harness knowledge for better wildfire management and improve wildfire risk assessments

- Update information on wildfire hazard, exposure and vulnerability regularly.
- Integrate climate models into wildfire hazard assessments.
- Develop wildfire projections that integrate information on future climate and socio-economic changes under different scenarios.
- Integrate policy-relevant knowledge on wildfires, including lessons learnt from extreme fires, into all relevant policies and practices.

Strengthen the policy and institutional framework

- Promote a whole-of-government approach to wildfire management; national, integrated wildfire risk management strategies and central co-ordinating agencies can be useful implementation vehicles.
- Integrate wildfire risk prevention across all relevant sectors, ensuring policy coherence and alignment, especially in land use, infrastructure development and forest management.
- Ensure the engagement of all relevant government agencies as well as the participation of relevant non-governmental stakeholders.
- Strengthen co-ordination, collaboration and knowledge exchange across sectors and levels of government through cross-governmental agencies or cross-sectoral platforms.

Scale up funding and risk transfer instruments for wildfire risk reduction

- Ensure sufficient and stable public funding for wildfire prevention and encourage private investment in wildfire risk reduction through incentives and subsidies.
- Encourage the provision and uptake of insurance covering wildfire risk and ensure its availability and affordability for assets and activities in high-risk areas that cannot be relocated.
- Develop compensation mechanisms that do not discourage *ex ante* investments in risk prevention, self-protection and insurance.

References

AGIF (2021), “Activity Report of the Integrated Rural Fire Management System – 2021”, Agency for the Integrated Management of Rural Fires, Portugal, https://www.agif.pt/pt/relatorio-de-atividades-sgifr-2021. [123]

APA (2020), *National Forestry Accounting Plan Portugal 2021-2025*, Portuguese Environment Agency, https://apambiente.pt/sites/default/files/_Clima/Mitiga%C3%A7%C3%A3o/Plano%20Contabilidade%20Florestal%20Nacional%202021-2025/National%20Forestry%20Accounting%20Plan_Revised%20version%20january%202020.pdf. [91]

Bank of Greece (2011), *The Environmental, Economic and Social Impacts of Climate Change in Greece*, Climate Change Impacts Study Commission, Bank of Greece, Athens, https://www.bankofgreece.gr/Publications/ClimateChange_FullReport_bm.pdf. [66]

Barquín, J. et al. (2022), “Monoculture plantations fuel fires amid heat waves”, *Science*, Vol. 377/6614, pp. 1498-1498, https://doi.org/10.1126/science.ade5923. [39]

Belleville, G., M. Ouellet and C. Morin (2019), “Post-traumatic stress among evacuees from the 2016 Fort McMurray wildfires: Exploration of psychological and sleep symptoms three months after the evacuation”, *International Journal of Environmental Research and Public Health*, Vol. 16/9, p. 1604, https://doi.org/10.3390/ijerph16091604. [15]

Blandford, D. (2019), ""Burn baby burn" – Controlling the risk of wildfires in Greece", Discussion paper prepared for the annual meetings of the Agricultural Economics Society at Warwick University, UK,, 15-17 April 2019, https://www.researchgate.net/publication/332472616_Burn_Baby_Burn_-Controlling_the_Risk_of_Wildfires_in_Greece. [106]

Boulton, C., T. Lenton and N. Boers (2022), "Pronounced loss of Amazon rainforest resilience since the early 2000s", *Nature Climate Change*, Vol. 12/3, pp. 271-278, https://doi.org/10.1038/s41558-022-01287-8. [30]

Bowman, D. et al. (2009), "Fire in the earth system", *Science*, Vol. 324/5926, pp. 481-484, https://doi.org/10.1126/science.1163886. [56]

Bowman, D. et al. (2020), "Vegetation fires in the Anthropocene", *Nature Reviews Earth & Environment*, Vol. 1, pp. 500-515, https://doi.org/10.1038/s43017-020-0085-3. [63]

Brasuell, J. (2021), "A new approach to wildfire resilience: Property buy backs, fire resistant parks", Planetizen, https://www.planetizen.com/news/2021/08/114455-new-approach-wildfire-resilience-property-buy-backs-fire-resistant-parks. [100]

Burrows, N. and L. McCaw (2013), "Prescribed burning in southwestern Australian forests", *Frontiers in Ecology and the Environment*, Vol. 11/S1, pp. e25-e34, https://doi.org/10.1890/120356. [93]

California Department of Insurance (n.d.), "Safer from wildfires", web page, https://www.insurance.ca.gov/01-consumers/200-wrr/saferfromwildfires.cfm (accessed on 5 February 2023). [126]

Campanharo, W. et al. (2019), "Translating fire impacts in southwestern Amazonia into economic costs", *Remote Sensing*, Vol. 11/7, p. 764, https://doi.org/10.3390/rs11070764. [23]

Canadell, J. et al. (2021), "Multi-decadal increase of forest burned area in Australia is linked to climate change", *Nature Communications*, Vol. 12/1, p. 6921, https://doi.org/10.1038/s41467-021-27225-4. [1]

Caohuu, D. et al. (2015), *Fueling Resilience: Climate and Wildfire Risk in the United States*, Swiss Reinsurance Company Ltd, Zurich, https://www.swissre.com/dam/jcr:c2345219-8148-49e6-99dd-c9be9f505301/pub_Fueling_resilience.pdf. [79]

Council of Ministers, Portugal (2020), *2020-2030 National Plan for Integrated Rural Fire Management*. [120]

Council of Ministers, Portugal (2015), *National Forestry Strategy*. [117]

Czajkowski, J. et al. (2020), *Application of Wildfire Mitigation to Insured Property Exposure*, CIPR Research Report, https://content.naic.org/sites/default/files/cipr_report_wildfire_mitigation.pdf (accessed on 9 March 2023). [108]

DGT (n.a.), *Wildfire Hazard Map (Carta de Perigosidade de Incêndio Rural)*, https://www.dgterritorio.gov.pt/paisagem/ptp/carta-perigosidade-incendio-rural (accessed on 12 July 2022). [115]

Edwards, R. et al. (2020), “Causes of Indonesia’s forest fires”, *World Development*, Vol. 127, p. 104717, https://doi.org/10.1016/j.worlddev.2019.104717. [12]

EFFIS (n.d.), “European Forest Fire Information System EFFIS”, https://effis.jrc.ec.europa.eu (accessed on 14 February 2023). [72]

Ellis, E. et al. (2021), “People have shaped most of terrestrial nature for at least 12,000 years”, *Proceedings of the National Academy of Sciences*, Vol. 118/17, https://doi.org/10.1073/pnas.2023483118. [44]

EM-DAT (2023), *Natural Disasters 2000-2023 (database)*, https://public.emdat.be (accessed on 1 March 2023). [6]

European Commission (2022), “Forest fires: €170 million to reinforce rescEU fleet”, https://civil-protection-humanitarian-aid.ec.europa.eu/news-stories/news/forest-fires-eu170-million-reinforce-resceu-fleet-2022-10-05_en#:~:text=Following%20a%20record%2Dbreaking%20forest,from%20the%20summer%20of%202023 (accessed on 9 March 2023). [70]

European Commission (2021), “Commission report on forest fires: Climate change is more noticeable every year”, https://ec.europa.eu/commission/presscorner/detail/en/ip_21_5627. [76]

European Commission (n.d.), *Global Wildfire Monitoring*, https://atmosphere.copernicus.eu/global-fire-monitoring (accessed on 16 February 2023). [73]

FAO (2021), *The Impact of Disasters and Crises on Agriculture and Food Security: 2021*, Food and Agriculture Organization, Rome, https://doi.org/10.4060/cb3673en. [26]

Fitzgerald, S. and M. Bennett (2013), *A Land Manager’s Guide for Creating Fire-Resistant Forests*, Oregon State University, https://www.nwfirescience.org/sites/default/files/publications/A%20Land%20Managers%20Guide%20for%20Creating%20Fire-resistant%20Forests%20.pdf. [90]

Ford, B. et al. (2018), “Future fire impacts on smoke concentrations, visibility, and health in the contiguous United States”, *GeoHealth*, Vol. 2/8, pp. 229-247, https://doi.org/10.1029/2018GH000144. [14]

Friedlingstein, P. et al. (2019), “Global carbon budget 2019”, *Earth System Science Data*, Vol. 11/4, pp. 1783-1838, https://doi.org/10.5194/essd-11-1783-2019. [57]

Galbraith, R. (2017), “The power of insurance incentives to promote fire adapted communities”, International Association of Wildland Fire, https://www.iawfonline.org/article/the-power-of-insurance-incentives-to-promote-fire-adapted-communities. [125]

GFMC (2019), *Conclusions and Proposals of the Independent Committee Tasked to Investigate the Underlying Causes and Explore the Perspectives for the Future Management of Landscape Fires in Greece*, Global Fire Monitoring Center, https://gfmc.online/wp-content/uploads/FLFM-DG-ECHO-Presentation-08-March-2019.pdf. [121]

GFMC (2019), *Report of the Independent Committee Established by Prime Ministerial Decision Y60 (Government Gazette 3937/B/2018) for the Analysis of the Underlying Causes and the Investigation of the Management Perspectives of Future Forest and Countryside Fires in Greece*, The Global fire Monitoring Center, https://government.gov.gr/wp-content/uploads/2019/02/independent_committee-compressed.pdf. [119]

Glauber, A. et al. (2016), "The cost of fire: An economic analysis of Indonesia's 2015 fire crisis", *Indonesia Sustainable Landscapes Knowledge Note No. 1*, World Bank, Jakarta, http://hdl.handle.net/10986/23840. [13]

Goss, M. et al. (2020), "Climate change is increasing the likelihood of extreme autumn wildfire conditions across California", *Environmental Research Letters*, Vol. 15/9, https://doi.org/10.1088/1748-9326/ab83a7. [54]

Government of Portugal (2021), *Portugal's Adaptation Communication to the United Nations Framework Convention on Climate Change*, https://unfccc.int/sites/default/files/resource/2021%20Portugal%20ADCOM_UNFCCC.pdf. [118]

Government of Portugal (2019), *National Adaptation Plan (NAP) for Climate Change (P-3AC)*. [113]

Halofsky, J., D. Peterson and B. Harvey (2020), "Changing wildfire, changing forests: The effects of climate change on fire regimes and vegetation in the Pacific Northwest, USA", *Fire Ecology*, Vol. 16/1, pp. 1-26, https://doi.org/10.1186/S42408-019-0062-8/FIGURES/4. [47]

Hellenic Republic (2021), "National Risk Assessment for Greece (NRA-GR)". [107]

Higuera, P. et al. (2023), "Shifting social-ecological fire regimes explain increasing structure loss from Western wildfires", *PNAS Nexus*, Vol. 2/3, https://doi.org/10.1093/pnasnexus/pgad005. [24]

Hincks, T. et al. (2013), "Risk assessment and management of wildfires", in Rougier, J., S. Sparks and L. Hill (eds.), *Risk and Uncertainty Assessment for Natural Hazards*, Cambridge University Press, Cambridge, https://doi.org/10.1017/CBO9781139047562.013. [27]

Hope, E. et al. (2016), "Wildfire suppression costs for Canada under a changing climate", *PLOS ONE*, Vol. 11/8, p. e0157425, https://doi.org/10.1371/journal.pone.0157425. [81]

Invasive Species Centre (2022), "Wildfires, climate change, and invasive species", web page, https://www.invasivespeciescentre.ca/wildfires-climate-change-and-invasive-species (accessed on 3 February 2023). [49]

IPCC (2022), *Climate Change 2022: Impacts, Adaptation and Vulnerability – Summary for Policymakers*, Intergovernmental Panel on Climate Change, https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_FinalDraft_FullReport.pdf. [45]

IPCC (2022), *Climate Change 2022: Mitigation to Climate Change*, Intergovernmental Panel on Climate Change, https://www.ipcc.ch/report/sixth-assessment-report-working-group-3. [110]

Jacome Felix Oom, D. et al. (2022), *Pan-European Wildfire Risk Assessment*, Publications Office of the European Union, Luxembourg, https://publications.jrc.ec.europa.eu/repository/handle/JRC130136 (accessed on 2 March 2023). [116]

Jerrett, M., A. Jina and M. Marlier (2022), "Up in smoke: California's greenhouse gas reductions could be wiped out by 2020 wildfires", *Environmental Pollution*, Vol. 310, p. 119888, https://doi.org/10.1016/j.envpol.2022.119888. [60]

Jones, M. et al. (2022), "Global and regional trends and drivers of fire under climate change", *Reviews of Geophysics*, Vol. 60/3, https://doi.org/10.1029/2020RG000726. [3]

Jones, M. et al. (2022), "Review: Wildfire under climate change", web page, https://mattwjones.co.uk/global-and-regional-trends-and-drivers-of-fire-under-climate-change/#technicals (accessed on 18 April 2023). [64]

Jones, M. et al. (2019), "Global fire emissions buffered by the production of pyrogenic carbon", *Nature Geoscience*, Vol. 12/9, pp. 742-747, https://doi.org/10.1038/s41561-019-0403-x. [55]

Karels, J. (2022), *Wildland Urban Interface: A Look at Issues and Resolutions*, Federal Emergency Management Agency, United States Fire Administration, Emmitsburg, MD, https://www.usfa.fema.gov/downloads/pdf/publications/wui-issues-resolutions-report.pdf. [25]

Kartsios, S. et al. (2021), "Numerical investigation of atmosphere-fire interactions during high-impact wildland fire events in Greece", *Atmospheric Research*, Vol. 247, p. 105253, https://doi.org/10.1016/j.atmosres.2020.105253. [5]

Kirchmeier-Young, M. et al. (2019), "Attribution of the influence of human-induced climate change on an extreme fire season", *Earth's Future*, Vol. 7/1, pp. 2-10, https://doi.org/10.1029/2018EF001050. [52]

Kocher, S. et al. (2017), "Governance of land use planning to reduce fire risk to homes Mediterranean France and California", *Land*, Vol. 6/2, https://doi.org/10.3390/land6020024. [104]

Komac, B. et al. (2020), *Evolving Risk of Wildfires in Europe - The Changing Nature of Wildfire Risk Calls for a Shift in Policy Focus from Suppression to Prevention*, European Science & Technology Advisory Group. [102]

Kunreuther, H. and E. St. Peter (2020), "Reducing California wildfire losses", University of Pennsylvania, https://riskcenter.wharton.upenn.edu/lab-notes/reducing-california-wildfire-losses. [101]

LAO (2021), *The 2020-21 Budget: Governor's Wildfire-Related Proposals*, Legislative Analyst's Office, Sacramento, CA, https://lao.ca.gov/Publications/Report/4172. [35]

Marsh & McLennan Companies (2019), *The Burning Issue: Managing Wildfire Risk*, Marsh & McLennan Companies, https://www.marshmclennan.com/content/dam/mmc-web/insights/publications/2019/oct/THE%20BURNING%20ISSUE%20-%20MANAGING%20WILDFIRE%20RISK__screen_final.pdf. [21]

Melvin, M. (2021), *2020 National Prescribed Fire Use Report*, Coalition of Prescribed Fire Councils, https://www.stateforesters.org/wp-content/uploads/2020/12/2020-Prescribed-Fire-Use-Report.pdf. [94]

Ministry of the Environment and Energy, Greece (2022), "Antinero Forest Preventive Clearing Program", press release, https://ypen.gov.gr/programma-proliptikon-katharismon-dason-antinero (accessed on 2 December 2022). [124]

Ministry of the Environment and Energy, Greece (2018), *National Forest Strategy (2018-2038)*, Ministry of the Environment and Energy, Athens. [77]

Montiel, C. and D. Kraus (eds.) (2010), "Best practices of fire use: Prescribed burning and suppression fire programmes in selected case-study regions in Europe", European Forest Instutute Research Report 24, European Forest Instutute, https://www.ucm.es/data/cont/docs/530-2013-10-15-efi_rr2449.pdf. [95]

Moreira, F. et al. (2020), “Wildfire management in Mediterranean-type regions: Paradigm change needed”, *Environmental Research Letters*, Vol. 15/1, p. 011001, https://doi.org/10.1088/1748-9326/AB541E. [40]

Moss, J. and D. Burkett (2020), *Social Justice and the Future of Fire Insurance in Australia*, Climate Transitions Series, https://climatejustice.co/wp-content/uploads/2020/05/The-Future-of-Fire-Insurance-in-Australia-2.pdf. [128]

Müller, M., L. Vilà-Vilardell and H. Vacik (2020), *Forest Fires in the Alps – State of Knowledge, Future Challenges and Options for an Integrated Fire Management*, EUSALP Action Group 8, https://www.alpine-region.eu/sites/default/files/uploads/result/2233/attachments/200213_forestfires_whitepaper_final_online.pdf. [99]

Myers, R. (2006), *Living with Fire – Sustaining Ecosystems & Livelihoods through Integrated Fire Management*, The Nature Conservancy, Tallahassee, FL, https://www.un-redd.org/sites/default/files/2022-08/Integrated_Fire_Management_Myers_2006.pdf. [78]

NASA (n.d.), *Wildland Fires*, https://appliedsciences.nasa.gov/what-we-do/wildfires (accessed on 16 February 2023). [74]

National Interagency Fire Center (n.d.), “Suppression costs (dataset)”, https://www.nifc.gov/fire-information/statistics/suppression-costs (accessed on 10 March 2023). [82]

Nikonovas, T. et al. (2020), “Near-complete loss of fire-resistant primary tropical forest cover in Sumatra and Kalimantan”, *Communications Earth & Environment*, Vol. 1/1, https://doi.org/10.1038/s43247-020-00069-4. [37]

North, M. et al. (2015), “Reform forest fire management: Agency incentives undermine policy effectiveness”, *Science*, Vol. 349/6254, pp. 1280-1281, https://doi.org/10.1126/science.aab235. [122]

OECD (2022), *Climate Tipping Points: Insights for Effective Policy Action*, OECD Publishing, Paris, https://doi.org/10.1787/abc5a69e-en. [31]

OECD (2021), *Enhancing Financial Protection against Catastrophe Risks: The Role of Catastrophe Risk Insurance Programmes*, OECD, Paris, https://www.oecd.org/daf/fin/insurance/Enhancing-financial-protection-against-catastrophe-risks.pdf. [129]

OECD (2021), *Managing Climate Risks, Facing up to Losses and Damages*, OECD Publishing, Paris, https://doi.org/10.1787/55ea1cc9-en. [97]

OECD (forthcoming), “Taming wildfires in the context of climate change: The case of Australia”, *OECD Environment Policy Papers*, OECD Publishing, Paris, forthcoming. [98]

OECD (forthcoming), “Taming wildfires in the context of climate change: The case of Greece”, *OECD Environment Policy Papers*, OECD Publishing, Paris, forthcoming. [43]

OECD (forthcoming), “Taming wildfires in the context of climate change: The case of Portugal”, *OECD Environment Policy Papers*, OECD Publishing, Paris, forthcoming. [92]

OECD (forthcoming), “Taming wildfires in the context of climate change: The case of United States”, *OECD Environment Policy Papers*, OECD Publishing, Paris, forthcoming. [71]

OECD/The World Bank (2019), *Fiscal Resilience to Natural Disasters: Lessons from Country Experiences*, OECD Publishing, Paris, https://doi.org/10.1787/27a4198a-en. [127]

Otrachshenko, V. and L. Nunes (2022), “Fire takes no vacation: Impact of fires on tourism”, *Environment and Development Economics*, Vol. 27/1, pp. 86-101, https://doi.org/10.1017/S1355770X21000012. [67]

Overpeck, J., S. Dean and W. Stapp (2018), “USA: Climate change is driving wildfires, and not just in California”, https://www.preventionweb.net/news/usa-climate-change-driving-wildfires-and-not-just-california. [50]

Pardo Ibarra, T. (2020), “What Colombia is learning from Venezuela about fire management”, Dialogo Chino, https://dialogochino.net/en/climate-energy/36931-what-colombia-is-learning-from-venezuela-about-fire-management. [96]

Parisien, M. et al. (2020), “Fire deficit increases wildfire risk for many communities in the Canadian boreal forest”, *Nature Communications*, Vol. 11/2121, pp. 1-9, https://doi.org/10.1038/s41467-020-15961-y. [75]

Park Williams, A. et al. (2019), “Observed impacts of anthropogenic climate change on wildfire in California”, *Earth’s Future*, Vol. 7/8, pp. 892-910, https://doi.org/10.1029/2019EF001210. [53]

Parks, S. and J. Abatzoglou (2020), “Warmer and drier fire seasons contribute to increases in area burned at high severity in western US forests from 1985 to 2017”, *Geophysical Research Letters*, Vol. 47/22, https://doi.org/10.1029/2020GL089858. [2]

Parliament of Victoria (2010), *2009 Victorian Bushfires Royal Commission, Final Report, Volume 1: The Fires and the Fire-related Deaths*, Victorian Government, http://royalcommission.vic.gov.au/Commission-Reports/Final-Report/Volume-1/Print-Friendly-Version.html. [36]

Pivello, V. et al. (2021), “Understanding Brazil’s catastrophic fires: Causes, consequences and policy needed to prevent future tragedies”, *Perspectives in Ecology and Conservation*, Vol. 19/3, pp. 233-255, https://doi.org/10.1016/j.pecon.2021.06.005. [38]

Presidency of the Council of Ministers, Portugal (2021), *Decree-Law No. 82/2021 of 13 October 2021*, https://dre.pt/dre/en/detail/decree-law/82-2021-172745163. [103]

Radeloff, V. et al. (2018), “Rapid growth of the US wildland-urban interface raises wildfire risk”, *Proceedings of the National Academy of Sciences*, Vol. 115/13, pp. 3314-3319, https://doi.org/10.1073/pnas.1718850115. [42]

Republic of South Africa (2022), *Working for Water (WfW) Programme*, https://www.dffe.gov.za/projectsprogrammes/wfw. [85]

Roman, J. (2018), “Build. Burn. Repeat?”, *NFPA Journal*, https://www.nfpa.org/News-and-Research/Publications-and-media/NFPA-Journal/2018/January-February-2018/Features/Build-Burn-Repeat. [109]

Roman, J., A. Verzoni and S. Sutherland (2020), “Greetings from the 2020 wildfire season”, *NFPA Journal*, https://www.nfpa.org/News-and-Research/Publications-and-media/NFPA-Journal/2020/November-December-2020/Features/Wildfire (accessed on 9 March 2023). [69]

Romps, D. et al. (2014), “Projected increase in lightning strikes in the United States due to global warming”, *Science*, Vol. 346/6211, pp. 851-854, https://doi.org/10.1126/science.1259100. [46]

Royal Commission (2020), *Interim Observations*, Royal Commission into National Natural Disaster Arrangements, Canberra, https://naturaldisaster.royalcommission.gov.au/publications/interim-observations-1. [7]

Scherer, S. (2021), “Canada orders rail restrictions to reduce wildfire risk”, Reuters, https://www.reuters.com/world/americas/canada-orders-rail-restrictions-reduce-wildfire-risk-2021-07-11. [111]

Silva, L. et al. (2020), “Mortality events resulting from Australia’s catastrophic fires threaten aquatic biota”, *Global Change Biology*, Vol. 26/10, pp. 5345-5350, https://doi.org/10.1111/gcb.15282. [19]

Stephens, S. et al. (2018), “Drought, tree mortality, and wildfire in forests adapted to frequent fire”, *BioScience*, Vol. 68/2, pp. 77-88, https://doi.org/10.1093/BIOSCI/BIX146. [48]

Stevens-Rumann, C. et al. (2018), “Evidence for declining forest resilience to wildfires under climate change”, *Ecology Letters*, Vol. 21/2, pp. 243-252, https://doi.org/10.1111/ele.12889. [20]

The Nature Conservancy and Aspen Institute (2023), *Roadmap for Wildfire Resilience: Solutions for a Paradigm Shift*, The Nature Conservancy and Aspen Institute, https://www.nature.org/content/dam/tnc/nature/en/documents/Wildfire_Resilience_Roadmap.pdf. [89]

The White House (2022), “Fact sheet: President Biden signs executive order to strengthen America’s forests, boost wildfire resilience, and combat global deforestation”, https://www.whitehouse.gov/briefing-room/statements-releases/2022/04/22/fact-sheet-president-biden-signs-executive-order-to-strengthen-americas-forests-boost-wildfire-resilience-and-combat-global-deforestation. [86]

Thomas, D. et al. (2017), “The costs and losses of wildfires: A literature review”, *NIST Special Publication*, Vol. 1215, https://doi.org/10.6028/NIST.SP.1215. [22]

Tobin-de la Puente, J. and A. Mitchell (eds.) (2021), *The Little Book of Investing in Nature*, Global Canopy, Oxford, https://globalcanopy.org/insights/publication/the-little-book-of-investing-in-nature. [83]

Triantis, L. (2022), “Normalising spatial vulnerability in the era of climate crisis? Private property, informality, and post-disaster planning in peri-urban east Attica/Greece”, *Planning Theory*, Vol. 22/1, https://doi.org/10.1177/14730952221098260. [105]

Turner, M. et al. (2019), “Short-interval severe fire erodes the resilience of subalpine lodgepole pine forests”, *Proceedings of the National Academy of Sciences of the United States of America*, Vol. 166/23, pp. 11319-11328, https://doi.org/10.1073/pnas.1902841116. [28]

Uda, S., L. Hein and D. Atmoko (2019), “Assessing the health impacts of peatland fires: A case study for Central Kalimantan, Indonesia”, *Environmental Science and Pollution Research*, Vol. 26/30, pp. 31315-31327, https://doi.org/10.1007/s11356-019-06264-x. [11]

UNEP (2022), *Frontiers 2022: Noise, Blazes and Mismatches – Emerging Issues of Environmental Concern*, United Nations Environment Programme, Nairobi, https://www.unep.org/resources/frontiers-2022-noise-blazes-and-mismatches (accessed on 18 April 2023). [61]

UNEP (2022), *Spreading like Wildfire – The Rising Threat of Extraordinary Landscape Fires*, A UNEP Rapid Response Assessment, United Nations Environment Programme, Nairobi. [4]

UNEP (2021), *Adaptation Gap Report 2020*, United Nations Environment Programme, https://www.unep.org/fr/resources/rapport-2020-sur-lecart-entre-les-besoins-et-les-perspectives-en-matiere-dadaptation. [84]

USDA (2022), *Confronting the Wildfire Crisis: A Strategy for Protecting Communities and Improving Resilience in America's Forests*, United States Department of Agriculture, Washington, DC, https://www.fs.usda.gov/sites/default/files/Confronting-Wildfire-Crisis.pdf. [9]

USDA (n.a.), "Wildfire hazard potential", https://www.firelab.org/project/wildfire-hazard-potential (accessed on 30 January 2023). [114]

van der Velde, I. et al. (2021), "Biomass burning combustion efficiency observed from space using measurements of CO and NO2 by the TROPOspheric Monitoring Instrument (TROPOMI)", *Atmospheric Chemistry and Physics*, Vol. 21/2, pp. 597-616, https://doi.org/10.5194/acp-21-597-2021. [59]

van Hensbergen, H. and J. Cedergren (2020), "Forest-related disasters – Three case studies and lessons for management of extreme events", *Forestry Working Paper*, No. 17, Food and Agriculture Organization, Rome, https://doi.org/10.4060/cb0686en. [18]

van Oldenborgh, G. et al. (2021), "Attribution of the Australian bushfire risk to anthropogenic climate change", *Natural Hazards and Earth System Sciences*, Vol. 21/3, pp. 941-960, https://doi.org/10.5194/nhess-21-941-2021. [51]

Veraverbeke, S. et al. (2021), *Global Fraction of Lightning Fires and Burned Area from Lightning*. [33]

Victoria State Government (2022), "Powerline Bushfire Safety Program", https://www.energy.vic.gov.au/safety/powerline-bushfire-safety-program#:~:text=Prioritising%20community%20safety%20by%20reducing,Program%20was%20established%20in%202011. [112]

Vitolo, C. et al. (2020), "ERA5-based global meteorological wildfire danger maps", *Scientific Data*, Vol. 7/216, pp. 1-11, https://doi.org/10.1038/s41597-020-0554-z. [8]

Ward, C. et al. (2021), "Smallholder perceptions of land restoration activities: Rewetting tropical peatland oil palm areas in Sumatra, Indonesia", *Regional Environmental Change*, Vol. 21/1, https://link.springer.com/article/10.1007/s10113-020-01737-z. [88]

Ward, M. et al. (2020), "Six million hectares of threatened species habitat up in smoke", The Conversation, https://theconversation.com/six-million-hectares-of-threatened-species-habitat-up-in-smoke-129438 (accessed on 13 March 2023). [16]

Wijaya, A. et al. (2016), "After record-breaking fires, can Indonesia's new policies turn down the heat?", web page, https://www.wri.org/insights/after-record-breaking-fires-can-indonesias-new-policies-turn-down-heat (accessed on 16 February 2023). [87]

World Bank (n.d.), "Rural population – Portugal", https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?locations=PT (accessed on 9 August 2022). [41]

WRI (2022), *New Data Confirms: Forest Fires Are Getting Worse*, World Resources Institute, https://www.wri.org/insights/global-trends-forest-fires?utm_campaign=wridigest&utm_source=wridigest-2022-12-21&utm_medium=email. [32]

WRI (2021), *The Latest Analysis on Global Forests & Tree Cover Loss*, Global Forest Review, World Resources Institute, https://research.wri.org/gfr/latest-analysis-deforestation-trends (accessed on 10 March 2023). [29]

WRI (2021), "The top 10 countries for total tree cover loss from 2001 to 2021", web page, World Resources Institute Research, https://research.wri.org/gfr/top-ten-lists (accessed on 14 March 2023). [17]

WWF (2020), *Fires, Forests and the Future: A Crisis Raging Out of Control?*, World Wildlife Fund, Gland, Switzerland, https://wwf.panda.org/wwf_news/?661151/fires2020report. [10]

WWF (2019), *The Mediterranean Burns*, World Wildlife Fund, http://awsassets.panda.org/downloads/wwf__the_mediterranean_burns_2019_eng_final.pdf. [34]

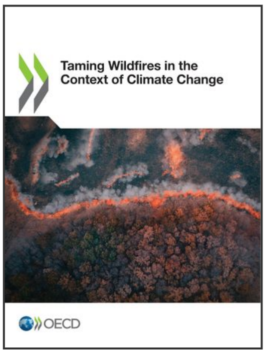
Xanthopoulos, G. (2008), "Who should be responsible for forest fires? Lessons from the Greek experience", *Proceedings of the Second International Symposium on Fire Economics, Planning, and Policy: A Global View*, https://www.researchgate.net/publication/237481246_Who_Should_Be_Responsible_for_Forest_Fires_Lessons_From_the_Greek_Experience1/link/5601114d08aeafc8ac8c7f6d/download. [68]

Xanthopoulos, G. and M. Athanasiou (2019), "Attica Region, Greece July 2018: A tale of two fires and a seaside tragedy", *Wildfire*, Vol. 28/2, pp. 18-21, https://www.iawfonline.org/wp-content/uploads/2019/04/28.2-April-2019-Wildfire-Magazine-Online.pdf. [80]

Xu, R. et al. (2020), "Wildfires, global climate change, and human health", *New England Journal of Medicine*, Vol. 383/22, pp. 2173-2181, https://doi.org/10.1056/NEJMsr2028985. [62]

Zheng, B. et al. (2021), "Increasing forest fire emissions despite the decline in global burned area", *Science Advances*, Vol. 7/39, https://doi.org/10.1126/sciadv.abh2646. [58]

Zou, Y. et al. (2020), "Using CESM-RESFire to understand climate-fire-ecosystem interactions and the implications for decadal climate variability", *Atmospheric Chemistry and Physics*, Vol. 20/2, pp. 995-1020, https://doi.org/10.5194/acp-20-995-2020. [65]



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