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FIRE EMERGENCY

NEW ZEALAND

Understanding wildfire carbon emissions and lessons for the fire and emergency agency

Literature review. Fire and emergency Report #213, July 2023

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Understanding wildfire carbon emissions and lessons for the fire and emergency agency

Literature Review

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Fire and Emergency Report #213

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Executive Summary

This literature review examines the relationship between wildfires and carbon emissions and the management strategies employed by fire and emergency agencies worldwide. The impact of wildfires on carbon emissions is explored, revealing that they release significant amounts of carbon dioxide (CO_2) and other greenhouse gases. This contributes to climate change. Factors such as fire size, intensity, and vegetation type influence the amount of carbon emissions. Forests and peatlands, which store substantial carbon, release large amounts of CO_2 when they burn. The loss of carbon sinks due to wildfires further exacerbates atmospheric CO_2 levels, adversely affecting global carbon levels and the environment.

Although wildfires are part of the natural carbon cycle, and can be carbon neutral in a healthy environment through plant regrowth, the literature review indicates that wildfires are not considered carbon neutral because they release substantial carbon emissions without a corresponding removal or offsetting mechanism.

Managing wildfires requires a coordinated effort from multiple stakeholders. While complete control is not always possible, strategies such as early detection and reporting, adequate firefighting resources and tactics, the incident command system, firebreaks and fuel management, community preparedness and education, collaboration and coordination, and research and technology advancements are all employed to minimise the spread and mitigate the impacts of wildfires.

This literature review provides valuable insights into the complex relationship between wildfires and carbon emissions, highlighting the need for further research and the importance of effective wildfire management strategies to protect communities, the economy, and the environment.

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1 Introduction

Fire and Emergency New Zealand (FENZ) commissioned Business and Economic Research Limited (BERL) to conduct a literature review to aid in understanding the relationship between wildfires and carbon emissions. This review aims to explore how overseas fire and emergency agencies deal with the management of wildfires, and the lessons FENZ can learn from overseas experiences.

A wildfire is defined as an unusual or extraordinary free-burning vegetation fire which may be started maliciously, accidentally, or through natural means, that negatively influences social, economic, or environmental values. In contrast, the landscape fires that we are more accustomed to are an integral part of our world, critical to the healthy functioning of many ecosystems, and an important cultural and land management tool. Whether caused by humans or nature, fires can become wildfires when they burn out of control. Table 1 below shows the main differences between landscape fires and wildfires.

Table 1 Main differences between landscape fires and wildfires

	Landscape fires	Wildfires
Frequency	Often seasonal, occur under moderate fire conditions	Linked to extreme fire weather
Intensity	Low to moderate intensity, with short episodes of high intensity	Mostly high intensity with some periods of moderate intensity
Suppressibility	Easily controlled with regular firefighting resources	Control measures may exceed regular firefighting resources
Impact	Low impact, with a positive impact on some species	High impact on one or more values (social, economic, environmental)

Source: UNEP (2022)

Alyson et al. (2016) investigated the effects of wildfires in the United States (USA) and observed that there were more than 100 large wildfires that burned an average of 1000 acres of land by each wildfire. Wildfires have significant impacts on both the economy and the environment. Wildfires can destroy homes, businesses, infrastructure, and agricultural lands, leading to significant financial and economic losses. National Centers for Environmental Information-National Oceanic and Atmospheric Administration (NOAA) assesses the cost of natural disasters and estimated that the cost of wildfires in the USA from 1980-2023 was about US$135 billion.[1]

[1] National Centers for Environmental Information, National Oceanic and Atmospheric Administration https://www.ncei.noaa.gov/access/billions/summary-stats

Wildfires can destroy natural habitats, displacing or causing harm to wildlife and plant species. This loss of biodiversity can have long-term ecological consequences. The smoke and ash generated by wildfires releases pollutants into the atmosphere, including carbon dioxide. This can lead to poor air quality and respiratory health issues for both humans and animals. When vegetation burns it releases carbon dioxide into the atmosphere, contributing to greenhouse gas emissions and exacerbating climate change.[2]

1.1 "Black-Summer" fire in Australia

The "Black-Summer" fire in Australia in 2019-2020 was one of the most devastating wildfires. Fires raged from September 2019 to March 2020 at an unprecedented scale; over 46 million acres of land were burned, approximately 3,500 homes were destroyed, and 34 people lost their lives.[3] The extreme bushfires released 715 million tonnes of carbon dioxide into the air (van der Velde et al., 2021). The fires were finally extinguished in March 2020, a long nine months after the first fire had broken out. The Australian Government's Department of Industry, Science and Resources (2020) estimated net emissions for the 2020 fire season, from the fires up to 11 February 2020, of around 830 million tonnes of carbon dioxide equivalent (MtCO2-e), using the Full Carbon Accounting Model (FullCAM) modelling framework. This summer black fires in 2020 have affected Australia's highest-biomass forests, which have an average above-ground biomass and debris estimated at around 300 tonnes per hectare. The fires are estimated to have burnt an average of around 20 per cent of the above-ground biomass and debris, resulting in average emissions of around 130 tonnes of CO2-e per hectare of forest burnt (Australian Government Department of Industry, Science and Resources, 2020).

1.2 Increasing number of extreme wildfires

Zheng et al. (2023) identified that carbon dioxide emissions from boreal forest fires have been increasing since at least the year 2000, reaching a new high in 2021. Although boreal fires typically produce about 10% of the global carbon dioxide emissions from wildfires, in 2021 they produced nearly one-quarter of the total. This abnormally high total resulted from the concurrence of water deficits in North America and Eurasia, which was an unusual situation. The increasing number of extreme wildfires, which is accompanying global warming, presents a real challenge to global climate change mitigation efforts.

1.3 Number of wildfires in New Zealand

New Zealand experiences between 4000-5000 vegetation fires per annum (FENZ, 2019). Figure 1 depicts the number of wildfires (blue line), and the area burnt (orange bars) for the last 36 years of wildfire records in New Zealand. Climate change modelling predicts that New Zealand will become hotter and drier overall, creating conditions that increase both the frequency and severity of wildfire events (Pearce et al., 2011; Scion, 2011; Watt et al., 2019).

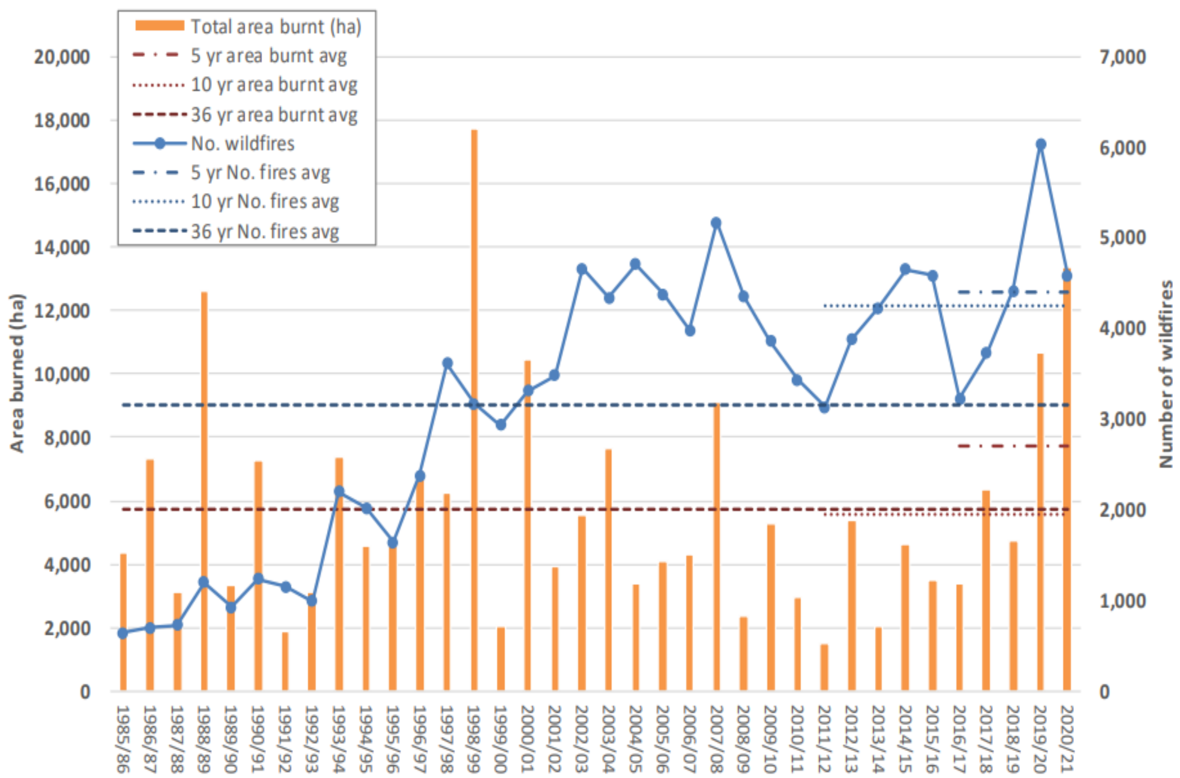
[2] Environmental Defense Fund (nd) https://www.edf.org/climate/heres-how-climate-change-affects-wildfires

[3] Australia after the bushfires: How forests and wildlife are recovering | Working Abroad

The New Zealand Wildfire Summary 2020/2021 was published by SCION (2022). The main findings are outlined below:

- There were 4,586 fires and 13,348 hectares (ha) burnt between 1 July 2020 and 27 June 2021
- The total area burnt was well above the 2019/20 season, and also well above the 5- and 10-year averages. Over the historical record (1985/86 - 2020/21) the average area burnt was 5,754 ha per year
- The last 5-year average for the total number of wildfires was 4,398, and the average area burnt was 7,703 ha
- The last 10-year average for the total number of wildfires was 4,245, and the average area burnt was 5,562 ha.

Figure 1 Number of wildfires and their impact (area burnt) for the last 36 years in New Zealand.



Source: FENZ (2022) New Zealand Wildfire Summary 2020/201 Update

1.4 Direct cost of wildfires on New Zealand's economy

Table 2 depicts some of the major wildfire events of the last few years, and their costs. The Nelson fires of 2019 and the Port Hills fire of 2017 were extreme; some of the biggest infernos seen in New Zealand this century. Extinguishing the Port Hills fire took 66 days, 14 helicopters, three fixed-wing planes, and hundreds of firefighters and members of the Defence Force. It burned 1660 hectares, forced the evacuation of 1400 people from 450 households, destroyed nine houses and damaged five, the biggest loss of people's homes to fire in 100 years.

Scion (2022) estimated that the direct cost of wildfires on New Zealand's economy in 2020 was $142 million, with indirect costs at least 2-3 times higher. Social impacts, and the loss of ecosystem services, were estimated to be up to 30-60 times higher than the direct costs. Scion (2022) also predicted that by 2050 direct costs could increase by 400 percent with a changing climate.

Table 2 Major catastrophic wildfires in Aotearoa New Zealand since 2017

Fire date	Area burned (ha)	Costs	House losses	Other impacts
Port Hills, Christchurch / Feb 2017	1660	$7.9M firefighting, $18.3M insurance claims	9 homes destroyed & several outbuildings, 450 homes & 2800+ people evacuated	1 fatality (helicopter pilot), 400+ ha commercial forest, Adventure Park impacted incl. gondola
Pigeon Valley, Nelson/Tasman Feb 2019	2316	$12.5M firefighting, $3.98 insurance claims	1 home destroyed, 3000+ people evacuated	1949 ha commercial forest burnt, forestry sector $2M/day in lost earnings
Deep Stream, Dunedin/ Nov 2019	4664		1 shed destroyed, 1 threatened house evacuated	1100 ha Conservation Park burned, 60% of city water catchment area
Pukaki Downs, Twizel/ Aug 2020	3110	$1.2M firefighting	1 home destroyed & several outbuildings, 8 properties + 200 day visitors & campers evacuated	Wilding carbon forest burnt, 80% of scientific reserve & part of wetland Conservation Area
Lake Ōhau, Twizel/ Oct 2020	5032	$1.6M firefighting, $35.8M insurance claims	45 homes destroyed + 3 sheds/garages (~half of homes in village lost), whole village self-evacuated	1900 ha Department of Conservation estate & small plantation burnt

Source: Compiled from Langer et al. (2021)

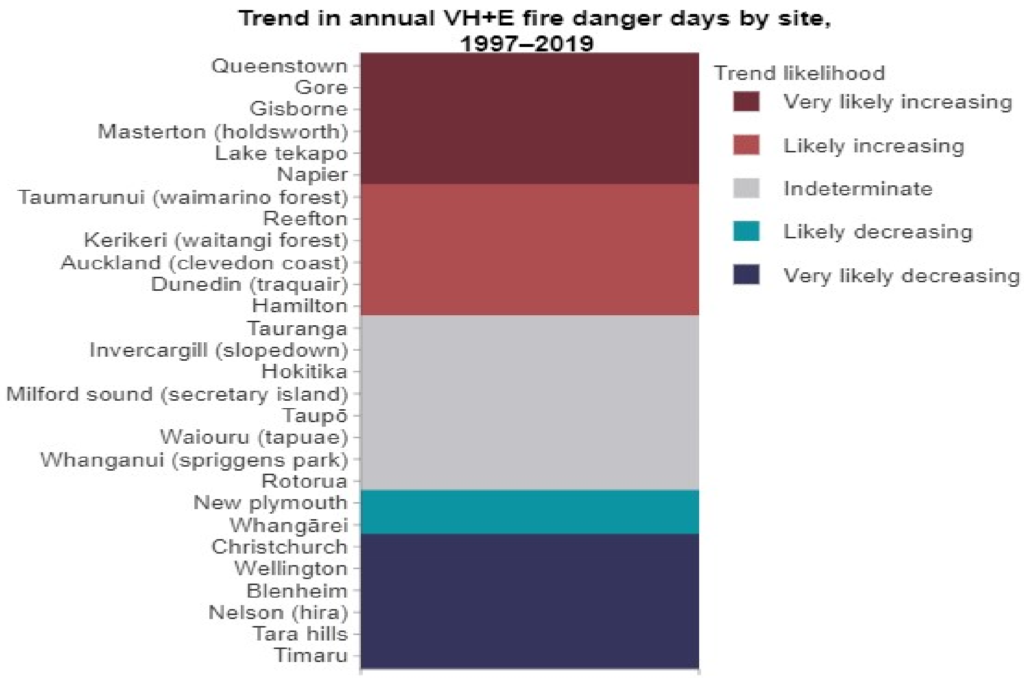
1.5 Wildfires and fire danger in New Zealand

Melia et al. (2022) simulated and predicted New Zealand's future wildfire weather conditions. They found that wildfire weather conditions will increase on average, both in wildfire season length and in the intensity of fires that may take hold, with the most severe wildfire dangers in the central-south inland areas of the South Island. They also found that the very-extreme conditions that led to the devastating 2019–2020 "Black-Summer" fires in Australia could occur in Aotearoa every 3–20 years for areas of the South Island (Mackenzie Country, Upper Otago, and Marlborough).

Pearce et al. (2011) estimated the effect of climate change on fire danger in New Zealand. They indicated that fire severity is likely to rise significantly with climate change in many parts of the country as a result of increases in temperature or wind speed, and lower rainfall. The areas most likely to experience increases from current levels are the east and south of the South Island, especially coastal Otago and Marlborough and south-eastern Southland, and the west of the North Island (particularly around Whanganui).

Figure 2 shows the trend in the number of days per year with 'very high and extreme' (VH+E) fire danger for a number of sites. This indicator measures fire danger, using the New Zealand Fire Danger Rating, at 28 sites around New Zealand from 1997 to 2019.

Figure 2 Trend in annual VH+E fire danger days by site



Source: Stats NZ

From 1997 to 2019 VH+E fire danger days, assessed as likely or very likely to impact all the 28 sites across New Zealand, while increased at 12 sites, decreased at eight sites, and eight sites were indeterminate.

For all 28 sites over the 10–year period from 2010 to 2019:

- the highest annual average number of VH+E fire danger days per year were at Lake Tekapo (36 days), Napier (30 days), Tara Hills (27 days), and Blenheim (23 days)
- the average annual number of VH+E fire risk days in January was 60 days, the highest annual average of all months, and the second-highest was in February, with an annual average of 36 days.

Against this backdrop, BERL undertook a literature review to investigate the impact of wildfires on carbon emissions, how overseas fire and emergency agencies deal with wildfire management, and what lessons New Zealand fire and emergency can learn from overseas experiences.

2 Review of the literature

To understand the relationship between wildfires and carbon emissions a targeted review of the literature on how wildfires impact the environment, and carbon emissions globally, has been conducted. We also explore how fire and emergency authorities deal with wildfires. The countries considered were Australia, the United Kingdom (UK), the United States of America (USA), and Canada.

This literature review addresses:

- how wildfires impact the environment and carbon emissions
- if and how wildfires are carbon neutral
- how wildfires impact the economy and social well-being.
- how fire and emergency authorities deal with wildfires.

This literature review explored wildfires and their environmental impact using the following sources:

- International organisations including the United Nations Environment Programme (UNEP), and the fire and emergency authorities of Australia, the USA, the UK, and Canada.
- Further information was sourced on wildfire and carbon emissions using Web of Science, and Scopus. The Web of Science includes a range of different types of publications including journal papers, websites, and conference proceedings. Scopus has an extensive abstract and citation database of peer-reviewed literature, scientific journals, books, and conference proceedings
- Electronic databases in international environmental, carbon emission, and climate-related journals were also explored using Google Scholar search

2.1 Wildfires and carbon emissions

Wildfires release carbon dioxide emissions and other greenhouse gases (GHG) that contribute to climate change. The amount of carbon emissions can vary depending on the size, intensity, and duration of the fire, as well as the types of vegetation being burned. These gases contribute to the greenhouse effect and global warming. However, it is challenging to determine how much wildfire emissions alter the GHG concentrations in the atmosphere and contribute to anthropogenic climate change because wildfire emissions are part of the terrestrial carbon cycle. Some key points regarding the impact of wildfires on carbon emissions are outlined below.

- **Carbon release:** The burning of organic matter, such as trees, plants, and vegetation, during wildfires releases carbon dioxide (CO2) that was stored in the biomass. Large, intense wildfires can release substantial amounts of carbon in a short period. The longer the fire burns, the more carbon emissions it produces
- **Vegetation type:** Different types of vegetation store varying amounts of carbon. Forests, for example, contain significant carbon stocks so when they burn the carbon release is substantial. Peatlands, which consist of partially decayed plant material, store even larger amounts of carbon and when they burn they release vast quantities of CO2

- **Loss of carbon sinks:** Wildfires can destroy forests and other ecosystems that act as carbon sinks, absorbing CO2 from the atmosphere through photosynthesis. When these carbon sinks are lost or damaged their ability to sequester carbon is diminished, which further contributes to increased atmospheric CO2 levels
- **Feedback loop:** Increased carbon emissions from wildfires can contribute to a positive feedback loop. As more carbon is released into the atmosphere it can contribute to climate change that, in turn, can create conditions conducive to more frequent and severe wildfires. This cycle can exacerbate the overall impact of wildfires on carbon emissions.

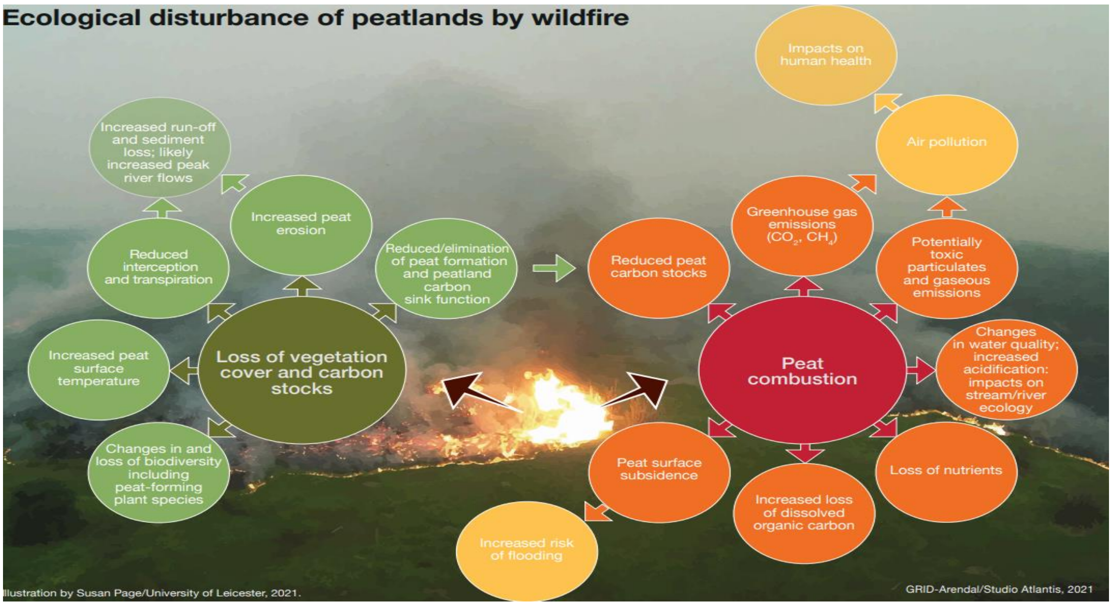
2.2 Carbon dioxide emissions from wildfires spiked in 2021

A team of Earth system scientists at the University of California, led by Zheng et al. in 2023, discovered that carbon dioxide emissions from wildfires have been rising gradually since 2000. In 2021, these emissions spiked dramatically, reaching a record high. The study found that burning boreal forests in North America and Eurasia released nearly half a gigaton of carbon (equivalent to 0.48 billion metric tons of CO2), the highest amount since 2000. This number was 150% higher than the average CO2 emissions between 2000 and 2020.

2.3 Impact of wildfires on peatland ecosystem

Wildfires have the potential to cause significant harm to both the environment and society. As illustrated in Figure 3, peatlands can suffer ecological damage as a result of wildfires. Peatlands play a vital role in storing carbon, preserving biodiversity, and providing ecosystem services such as water. However, they are prone to fires, which can be difficult to extinguish and result in various ecological, hydrological, and social consequences.

Figure 3 Impact of wildfires on ecosystem



Source: UNEP (2022)

2.4 Southeast Australia extensive wildfires

Southeast Australia experienced intense and geographically extensive wildfires during the 2019–2020 summer season (Abram et al., 2021). Although fires occur regularly in the savannas in northern Australia, the recent episodes were extremely large in scale and intensity, burning unusually large areas of eucalyptus forest in the southeast. The fires released substantial amounts of carbon dioxide into the atmosphere. Using satellite observations of carbon monoxide, emissions of carbon dioxide were estimated to be 715 million tonnes (715 teragrams) from November 2019 to January 2020 (van der Velde et al., 2021). The increase in carbon emissions from wildfires can contribute to a positive feedback loop, exacerbating climate change and creating conditions for more frequent and severe fires. Recent studies have shown record-high carbon emissions from wildfires, such as those in boreal forests and in Southeast Australia.

2.5 California wildfires and their impact

California's Air Resources Board (CARB) estimated GHG emissions from wildfires, and published this information for the years from 2000-2019. Using fire footprint information CARB has also released a draft estimate of wildfire GHG emissions in 2020, which was the worst fire year on record (by acres burned) for the State of California. The emissions estimate, 112 million metric tons of CO2, is equivalent to the amount of carbon contained in the structural lumber of 6.3 million average California homes, or over 75 percent of all homes in California.

Grennan, et al. (20023) showed that people who had been directly impacted by the fire, for example by losing property or having to flee flames, and those who simply witnessed the fires in their community, both experienced similar cognitive impairments. A recent study of 725 Californians showed that individuals who were directly exposed to California's deadliest wildfire, the Camp Fire of 2018, had significantly greater chronic symptoms of post-traumatic stress disorder, anxiety, and depression, than control individuals not exposed to the fires. Fire-exposed individuals showed significant cognitive deficits, particularly on the interference processing task and the greater stimulus-evoked frontoparietal activity, as measured on this task.

2.6 Canadian forest fires

Amiro et al. (2011) estimated direct carbon emissions from Canadian forest fires between 1959 and 1999, and found that an average of 2 million hectares of land was burned annually. The boreal ecozones experienced the most significant area burned. The mean fuel consumption for all fires was 2.6 kg of dry fuel per square metre, resulting in an average annual estimate of 27 teragrams (27 million tonne) of carbon emissions. These direct emissions accounted for about 18% of the CO2 emissions from the Canadian energy sector on average, but there was wide variation over the years. It is important to consider post-fire effects, and their impact on carbon loss and forest sink conditions, when assessing the overall carbon balance and climate implications of wildfires.

The above section indicates that wildfires contribute to carbon dioxide (CO2) emissions and other greenhouse gases (GHGs), which contribute to climate change. The amount of carbon emissions released during wildfires can vary depending on factors such as fire size, intensity, and vegetation type. Large and intense wildfires can release substantial amounts of carbon in a short period, particularly when forests and peatlands burn. Wildfires also impact carbon sinks, such as forests, reducing their capacity to absorb CO_2. This can create a positive feedback loop, where increased carbon emissions contribute to climate change, which in turn can lead to more frequent and severe wildfires. Recent studies have shown record-high carbon emissions from wildfires, including in boreal forests and Southeast Australia. In regions like California and Canada wildfires have significant impacts on carbon emissions, and can have detrimental effects on mental health and cognitive function in affected individuals. Understanding the impact of wildfires on carbon emissions is crucial for assessing their role in climate change and implementing effective mitigation strategies.

2.7 Are wildfires carbon neutral?

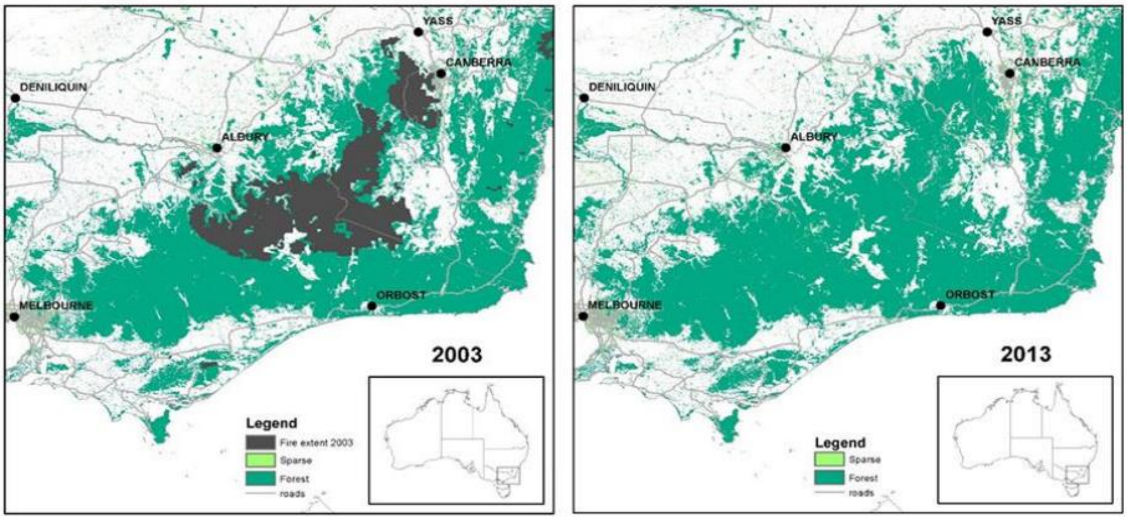
Carbon neutrality refers to achieving a balance between the amount of CO_2 emitted and the amount removed from the atmosphere through natural or artificial means. Wildfires, by their nature, release significant amounts of CO_2 without a corresponding removal or offsetting mechanism, making them a net source of carbon emissions rather than carbon-neutral events.

Therefore, wildfires are not considered carbon neutral because they release significant amounts of carbon dioxide (CO_2) and other greenhouse gases into the atmosphere. When organic matter, such as trees and vegetation, burns during a wildfire, the carbon stored in that biomass is released as CO_2. This contributes to the greenhouse effect and climate change.

While it is true that forests and ecosystems have the capacity to absorb and store carbon, the carbon released during a wildfire far outweighs any potential carbon sequestration that may occur afterwards. Additionally, the loss of vegetation and carbon sinks due to wildfires can further exacerbate carbon emissions and reduce the earth's capacity to absorb CO_2.

However, the carbon emissions from wildfires are considered part of the natural carbon cycle. In a balanced ecosystem, the carbon released by wildfires would be reabsorbed by plants and trees as they regrow, thereby creating a carbon-neutral cycle. Over time, the carbon emitted by wildfires would be offset by the carbon sequestered by new vegetation. However, wildfires can have indirect effects on carbon neutrality. For example, when fires burn through peatlands or forests, they can release large amounts of stored carbon that has accumulated over centuries or even millennia. Once this carbon is released into the atmosphere, it cannot be quickly reabsorbed, leading to a net increase in greenhouse gas concentrations.

Figure 4 Forest cover before and after 2002-03 bushfires



Source: Australian Government Department of Industry (2020)

Generally, over time and in the absence of new disturbances, forests re-absorb carbon to balance the carbon emitted during fires. Forests burnt this year are expected to continue sequestering carbon over the next decade and beyond as they recover. The Australian Government Department of Industry (2020) estimated post-fire carbon sequestration, using satellite data and the FullCAM model, and highlighted that more than 98 percent of forest cover was observed to return within 10 years after the 2002/03 bushfires (Figure 4).

Ribeiro-Kumara et al. (2020) reviewed how forest fires affect soil greenhouse gas emissions in upland boreal forests. Wildfires play a crucial role in carbon cycling and storage in boreal forests, accounting for nearly 10% of global fire carbon emissions. They identified that soil respiration emissions tend to stabilize between 10 and 30 years after the wildfire. Most forests are in upland soils with widespread permafrost, which may alter the greenhouse gas budgets and trigger unprecedented changes in the global carbon balance. They found that fires have negligible effects on methane (CH_4) fluxes, but permafrost thawing could turn upland boreal soils into temporary CH_4 sources. They also indicated that the temperature sensitivity of denitrification exceeds that of soil respiration, suggesting that the effects of warming on soil N_2O emissions may be greater than on carbon emissions.

Flanagan et al. (2019) simulated how carbon and species dynamics differ under fire exclusion, prescribed fire, and multiple wildfire scenarios. They found that all scenarios, except fire exclusion, resulted in net emissions to the atmosphere, but prescribed fire produced the least carbon emissions and maintained the most stable above-ground biomass compared to the wildfire scenario. Removing fire for approximately a century was necessary to obtain an average stand-level biomass greater than that of prescribed fire, and net emissions less than that of prescribed fire. The prescribed fire scenario produced a longleaf pine-dominated forest, the exclusion scenario converted to predominantly oak species, while scenarios with intermediate wildfire regimes supported a mix of other fire-facilitator hardwoods and pine species. Overall, this study supports prescribed fire regimes in the Southeastern United States Pinelands to both minimise carbon emissions and preserve native biodiversity.

Bastin et al. (2019) concluded that restoring forested land is the most effective approach to mitigating climate change. They found that reforestation on a global scale can help capture atmospheric carbon and reduce the impact of climate change. To estimate the potential for forest restoration across the world, Bastin et al. (2019) utilised direct measurements of forest cover to create a model. Their findings also indicated that wildfires that burn down forests have a considerable negative impact on carbon emissions.

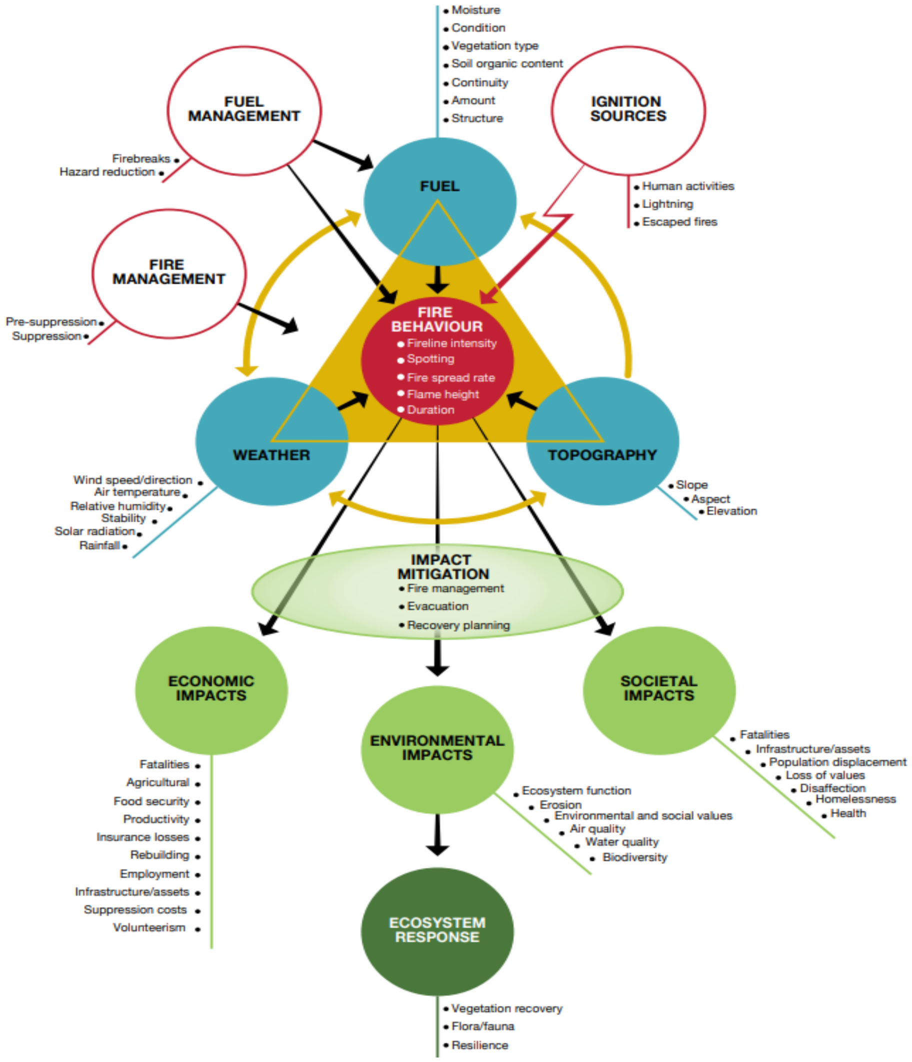
While wildfires are part of the natural carbon cycle, their effects on carbon neutrality can be indirect. When fires burn through carbon-rich areas like peatlands or forests, they can release stored carbon that has accumulated over long periods. This carbon cannot be rapidly reabsorbed, resulting in a net increase in greenhouse gas concentrations. However, over time and without new disturbances, forests can reabsorb carbon, balancing the carbon emitted during fires.

In summary, wildfires release CO2 and other greenhouse gases into the atmosphere contributing to climate change. Wildfires are part of the natural carbon cycle, and the carbon emissions from wildfires can be offset over time as forests regrow and reabsorb carbon. However, while wildfires burn they release large amounts of stored carbon. This released carbon cannot be quickly reabsorbed, leading to a net increase in greenhouse gas concentrations. Overall, wildfires are not considered carbon neutral because they release substantial carbon emissions without a corresponding removal or offsetting mechanism.

3 Factors influencing wildfire outcomes and management options

Several factors influence wildfire outcomes, including weather conditions, vegetation, topography of land, and forest and environmental climate. It is important to consider all these factors comprehensively when assessing wildfire risk, developing fire management strategies, and implementing mitigation measures to minimise the social, economic, and ecological impacts of wildfires. However, in New Zealand, the main reason for wildfires is human activities. According to MPI (2023), 99 percent of wildfires in New Zealand, are caused by humans.[4]

Figure 5 Factors that influence wildfire outcomes and management options



Source: UNEP (2022)

Figure 5 shows the factors influencing wildfires outcomes and management options (UNEP, 2022). A wildfire is the result of a complex interaction of biological, meteorological, physical, and social

[4] How wildfires start, https://www.mpi.govt.nz/forestry/protecting-forests-from-summer-wildfires/

factors that influence its likelihood, behaviour, duration, extent, and outcome (i.e., severity or impact). Changes in many of these factors are increasing the risk of wildfires globally (e.g., climate change is increasing the frequency and severity of weather conducive to wildfire outbreaks, and changed demographics in high-risk regions are increasing the potential impacts of wildfires). Management options at junctures, such as fuel management (managing fuels prior to a wildfire occurrence), fire management, or relocating those threatened during a wildfire event (e.g., evacuation), can mitigate some of the economic, environmental, or societal impacts of wildfire, but it is impossible to mitigate all risks for all fires. As a result, communities often have to learn to live with the residual risk of wildfires.

3.1 Dealing with wildfires

Dealing with wildfires requires a comprehensive approach that involves prevention, preparedness, response, and recovery efforts. Here are some key strategies and measures for dealing with wildfires:

Prevention

Implement strict regulations and guidelines for activities that can cause wildfires, such as campfires, debris burning, and fireworks. Conduct controlled or prescribed burns to reduce fuel loads and prevent the build-up of flammable vegetation. Promote public awareness and education on fire safety and responsible behaviour in fire-prone areas. Implement and maintain fire breaks and fuel breaks to create barriers that can help control the spread of wildfires.

Preparedness

Develop and regularly update emergency response plans and procedures for wildfires. Establish early warning systems and effective communication networks to alert communities about potential fire threats. Conduct regular training and drills for emergency responders and communities to ensure preparedness and coordination. Develop and maintain evacuation plans and routes, and educate residents on evacuation procedures.

Response

Establish a well-coordinated incident command system to manage firefighting efforts and resources. Mobilise and deploy trained firefighting personnel, equipment, and aircraft to quickly respond to wildfires. Employ firefighting strategies such as fire suppression, containment, and creating fire breaks to control and extinguish wildfires. Coordinate with local, regional, and national agencies, as well as mutual aid agreements, for additional resources and support during large-scale incidents.

Recovery

Assess the damage caused by wildfires and prioritise the restoration of critical infrastructure and ecosystems. Provide support and resources for affected communities, including temporary shelter, food, and medical assistance. Implement rehabilitation and reforestation programmes to restore and enhance the affected areas' ecological health. Conduct post-fire assessments and studies to learn from the event and improve future wildfire management strategies.

Research and innovation

Invest in research and technology development for advanced fire detection and monitoring systems.

Promote the use of remote sensing, satellite imagery, and modelling tools to predict fire behaviour and identify high-risk areas. Explore and implement new firefighting techniques, such as the use of unmanned aerial vehicles (drones) and specialised firefighting equipment. Support research on climate change impacts and mitigation strategies to address the underlying factors that contribute to wildfire risk.

3.2 Australia and New Zealand's forest fire management group

Australia and New Zealand's Forest Fire Management Group (2013) recommended some policy guidelines on forest wildfire management. They suggested integrated rural land and forest management policies. Legislation and policies related to fire, rural land, and forest management should be coordinated across the relevant institutions and organisations, and with communities.

The approach suggested by Wildfire Prevention Australia (2022) emphasised a holistic approach to dealing with wildfires, similar to the recommendations made by the United Nations Intergovernmental Panel on Climate Change (UNIPCC). It includes various strategies such as land management and community education, underscoring the importance of comprehensive measures to mitigate wildfire risks. Overall, these guidelines stressed the significance of integrated policies, community engagement, and proactive measures to effectively manage and reduce the impact of wildfires.

3.3 FENZ strategy for climate change and wildfires

FENZ developed a strategic road map titled "Our Climate Response Strategy 2022—2030" to manage its carbon footprint and address the challenges of climate change. The strategy outlined how FENZ will manage its carbon footprint, and how it will respond to the challenges of climate change through to 2030. It focused on the key areas where carbon emissions can be reduced, and how FENZ can adapt to the ongoing and expected impacts of climate change. The key issues are to:

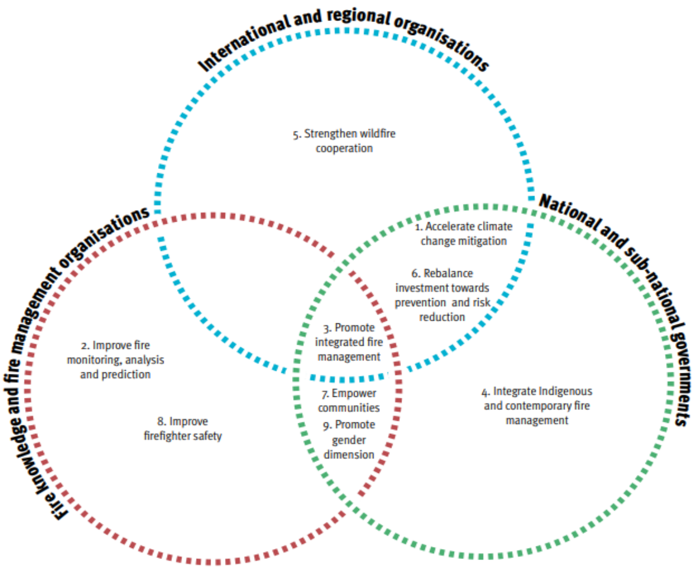
- define emissions profile, especially red fleet emissions profile
- identify sources of these emissions and how they contribute to the carbon footprint
- decide on key areas to focus on to reduce carbon emissions
- decide on actions to take to adapt to the impacts of climate change.

It should be noted that the strategy does not provide specific measures for managing wildfires.

3.4 United Nations Intergovernmental Panel on Climate Change (UNIPCC) guideline

According to the UNIPCC report of 2022, weather conditions conducive to wildfires are becoming more frequent and will continue to increase with higher global warming levels.

Figure 6 Dealing with wildfires



Source: UNEP (2022)

The report recommends holistic actions to reduce the social, economic, and ecological impact of wildfires. These actions include recognising and responding to the impact of climate change on wildfires, understanding wildfire behaviour, improving fuel management and monitoring, promoting integrated fire management, strengthening international cooperation on wildfires, empowering communities and local authorities, and improving firefighter safety (Figure 6).

The UNIPCC recommendations to reduce the social, economic, and ecological impact of wildfires are as follows:

- Recognise and respond to the impact of climate change on the prevalence and behaviour of wildfires
- Understand wildfire behaviour and improve fuel management and wildfire monitoring
- Promote an integrated fire management approach
- Support and integrate Indigenous, traditional, and contemporary fire management practices into policy
- Strengthen international and regional cooperation on wildfires
- Rebalance investments spent on reactive suppression to proactive wildfire mitigation and management
- Empower communities and local authorities
- Improve firefighter safety

- Promote the collection of data and information on the gender dimension of wildfires.

3.5 Canadian approach to dealing with wildfires

On 8 June 2023 there were 437 active wildfires across Canada, according to the Canadian Interagency Forest Fire Centre. As of 9 June, roughly 9.4 million acres had burned and more than 20,000 people had been evacuated.[5]

To establish a balanced approach federal, provincial, and territorial governments developed the Canadian Wildland Fire Strategy (CWFS). The strategy charts the future of fire management and includes measures to mitigate hazards and improve fire preparedness, response, and recovery capabilities. Canadians realise that it is not economically possible or ecologically desirable to eliminate all wildland fires.

The Canadian government also prepared the following fire managers' toolkit to deal with bushfires:

- The comprehensive Canadian Wildland Fire Information System (CWFIS) provides data and maps of fire danger conditions across Canada. Fire management agencies, forest companies, and researchers are also increasingly using the Canadian Forest Fire Danger Rating System (CFFDRS) to assess the role and impact of fire in forest ecosystems.
- The Wildfire Threat Rating System (WTRS) assesses and maps four main components of fire risk; ignition, values at risk, suppression capability, and expected fire behaviour. The system generates an overall fire-threat rating that helps forest managers determine how land-use decisions affect the fire threat in a given area.
- The Canadian Forest Service has developed a diverse set of fire models and applications. The modelling tools range from hourly predictions of fire growth in forest stands, to assessments of the fire-susceptibility of landscapes over several fire seasons or even over multiple years. For example, the Canadian Fire Effects Model (CanFIRE) can be used to predict the behaviour of a wildland fire that is underway. This can help authorities plan daily suppression tactics.
- The Probabilistic Fire Analysis System (PFAS) is a long-range fire growth model that predicts the potential extent of a wildfire if it were allowed to grow unimpeded for weeks or even months. The model combines the probability of a fire's spread with the probability of its survival up until rain or snow puts it out naturally.
- Other important resources for fire managers are programmes designed to encourage individuals, businesses, and communities to become involved in fire management. For example, the FireSmart initiative includes a risk reduction programme for forestry companies. It identifies operational measures (for harvest scheduling, cutting, road layout, and regeneration and stand-tending activities) that will reduce the risk of damage from unwanted wildland fires. These measures are also aimed at mitigating the risks associated with prescribed fires.

[5] Canadian Interagency Forest Fire Centre (CIFFC) https://ciffc.net

3.6 Western Australia bushfires guidelines

The Department of Fire and Emergency Services (DFES) protects all of the Western Australia (WA) community against the unpredictability of natural hazards, emergency incidents, and bushfires. It operates 24 hours per day and seven days per week, on land, in the air, and by sea across the state. The DFES has prepared extensive guidelines to combat bushfires and some of the major guidelines are shown in Figure 6.

Figure 7 Dealing with bushfires in Australia.

Source: Department of Western Australia https://www.dfes.wa.gov.au/hazard-information/bushfire

3.7 Wildfires management in the United States: Wildfires 101 & 102

The policy guidelines discussed in "Wildfires in the United States 101: Context and Consequences" and "Wildfires in the United States 102: Policy and Solutions" focus on reducing the negative impacts of wildfires in the United States. The key policy tools highlighted include:

Emissions Reduction: Addressing climate change, a primary driver of increasing wildfire activity, through policies that aim to reduce greenhouse gas emissions.

Fuels Management: Implementing fuel treatments to reduce the accumulation of vegetation in fire-prone areas, which can slow the spread and intensity of fires.

Emergency Response: Providing increased support, resources, and benefits for firefighters to effectively manage more intense fire seasons and reduce turnover and burnout.

Limiting Ignitions: Raising awareness and imposing restrictions on activities that can cause human-ignited fires, such as debris burning, arson, vehicle-related incidents, campfires, and fireworks.

Role of Utilities: Enacting policies that require utilities to shut off power during high fire danger conditions, and implementing measures to remove hazardous fuel near power lines and improve transmission equipment.

Land Use, Exposure, and Vulnerability: Mitigating fire risk by considering factors such as the likelihood of fire, the value of property at risk, and the vulnerability of structures to damage. Insurance markets can also help individuals and businesses cope with remaining risks.

Addressing the Wildland-Urban Interface: Implementing zoning changes to encourage high-density housing development closer to urban centres, reducing the growth of the wildland-urban interface. This approach also addresses housing needs, reduces air pollution, and lowers greenhouse gas emissions from transportation.

Hardening Structures: Enforcing building codes that require new construction in high fire hazard areas to incorporate fire-resistant materials and precautions, reducing the structural and economic damage caused by wildfires.

Wildfires and Home Insurance: Recognising the challenges homeowners face in obtaining affordable home insurance due to increasing wildfire damages and exploring solutions to mitigate this issue.

Additional Policy Considerations: Considering the impacts of smoke on human health and investing in fuels management to reduce smoke intensity during wildfires, as well as exploring the benefits of prescribed fires and managed wildfires in controlling smoke emissions.

These policy tools aim to address the increasing frequency and severity of wildfires in the United States and minimise their negative impacts on communities, the environment, and public health.

3.8 SCION and FENZ policy recommendations

Langer et al. (2021) identified a list of wildfire risk reduction, mitigation, and preparedness actions to support agencies in their communications and engagement with people and communities in the rural-urban interface. The recommendations were developed based on a systematic review of over 120 international publications to identify best-practice advice for wildfire risk reduction, mitigation, and preparedness. The list has been grouped into actions to be implemented at different stages as is indicated below:

When building or remodelling a home

- Building design and construction
- Access and firefighter aid
- Walls and structure
- General safety features
- Windows and doors, roofs, decks and balconies, vents, chimneys and openings
- Utilities, sprinkles, water /shelters

When landscaping or designing outdoor spaces and property infrastructure

- Landscaping and defensible space
- Landscaping concepts
- Landscaping zone

When planning for wildfire evacuation

- Personal and household planning
- Household evacuation escape routes
- Safe meeting locations
- Community planning and coordination

When preparing for the start of each wildfire season

- Access and firefighter aid, maintain at least a 4-metre wide by 4- metre-high clearance.
- No storage of any firewood, fuels, or other flammable objects under or next to a house
- House and evacuation preparation

When a wildfire occurs

- Evacuate as early as possible, do not jeopardise your life under any circumstance
- Implement your household emergency plan, and take your emergency evacuation kit
- Check the radio, internet, and social media for fire updates and evacuation advice from fire and emergency agencies.

SCION recommendations to review

- Federal Emergency Management Agency, 2008: Defensible Space: Home Builder's Guide to Construction in Wildfire Zones
- Federal Emergency Management Agency, 2014: How to Prepare for a Wildfire.

3.9 Fire resistant plantation[6]

To decrease the likelihood of extreme wildfires altering the fuel component of the fire environment is crucial. One effective method is planting species that do not easily ignite as buffers around homesteads and forest blocks as suggested by the New Zealand Farm Forest New Zealand. Trees and shrubs with high moisture and salt content, low volatile oil content, smooth bark, and broad fleshy leaves are known to be highly fire-resistant. Some examples of such species include Griselinia, Coprosma, Pseudopanax, ngaio, koromiko, mahoe, lemonwood, and tree fuschia. A 10 to 20-metre wide planting of these species can provide protection, as they do eventually burn but not easily. Additionally, planting buffer species can enhance biodiversity and create habitats and food sources for native birds and animals. However, species like manuka and kanuka should be avoided as they ignite easily and burn intensely.

Overall, the focus is on reducing carbon emissions, adapting to climate change impacts, and implementing measures to reduce the social, economic, and ecological impact of wildfires through improved management, collaboration, and community engagement.

[6] Farm Forest New Zealand, https://www.nzffa.org.nz/farm-forestry-model/resource-centre/tree-grower-articles/may-2015/forests-farms-and-fire

4 Concluding remarks

The main aim of this literature scan is to understand the relationship between wildfires and carbon emissions. Moreover, an effort has been made to comprehend how emergency and fire agencies around the world manage wildfires.

We first highlighted the distinction between landscape fires and wildfires, with wildfires being more intense, occurring under extreme fire weather conditions, and having higher impacts on social, economic, and environmental values. It is worth mentioning the devastating "Black-Summer" fire that occurred in Australia in 2019-2020, which burned a significant amount of land and caused loss of life and property.

The literature review focuses on various aspects related to wildfires including: their impact on carbon emissions and ecosystems; their carbon neutrality in natural ecosystems; their effects on the economy and social well-being; and their handling by fire and emergency authorities. The review includes information from international organisations such as the United Nations Environment Programme (UNEP), and fire and emergency authorities in Australia, the United States, and Canada.

Regarding the impact of wildfires on carbon emissions, the literature review indicated that wildfires release carbon dioxide (CO2) and other greenhouse gases, contributing to climate change. The amount of carbon emissions depends on factors such as fire size, intensity, and vegetation type. Forests and peatlands store significant amounts of carbon, so when they burn, large amounts of CO2 are released. The loss of carbon sinks due to wildfires further contributes to increased atmospheric CO2 levels. The review suggests that wildfire carbon emissions have substantial adverse effects on global carbon levels and on the environment.

Wildfires are part of the natural carbon cycle, and the carbon emissions from wildfires can be offset over time as forests regrow and reabsorb carbon. However, while wildfires burn they release large amounts of stored carbon. This released carbon cannot be quickly reabsorbed, leading to a net increase in greenhouse gas concentrations. Overall, wildfires are not considered carbon neutral because they release substantial carbon emissions without a corresponding removal or offsetting mechanism.

Controlling wildfires is a complex and challenging task that requires a coordinated effort from various stakeholders. Complete control over wildfires is not always possible, and so the focus is primarily on managing and suppressing fires to minimise their spread and mitigate their impacts. Some key approaches and strategies used to control wildfires as suggested by UNEP (2022) are as follows:

- Early detection and reporting: Early detection is crucial in responding to wildfires promptly. Utilising surveillance systems, such as aerial patrols, lookout towers, drones, and satellite monitoring, can help identify fires in their early stages. Prompt reporting of wildfires to fire management authorities ensures a rapid response.
- Firefighting resources and tactics: Deploying adequate firefighting resources is essential for effective fire control. This includes trained firefighting personnel, fire engines, aircraft (such as helicopters and air tankers), and specialised equipment. Firefighters

employ various tactics, including direct attack (applying water or retardant directly to the flames), indirect attack (creating firebreaks or controlled burns to contain the fire's spread), and backburning (starting small fires to consume fuel ahead of the main fire).

- Incident command system (ICS): The ICS is a standardised management structure used to organise and coordinate firefighting efforts. It ensures clear communication, efficient resource allocation, and effective decision-making among different agencies and personnel involved in firefighting operations.
- Firebreaks and fuel management: Creating firebreaks, which are cleared areas devoid of vegetation, can help control the spread of wildfires by depriving them of fuel. Controlled burns or prescribed fires are used to remove excess vegetation and reduce fuel loads in fire-prone areas. Fuel management strategies aim to modify the landscape to minimise the intensity and impact of wildfires.
- Community preparedness and education: Educating communities on fire safety, evacuation procedures, and creating defensible spaces around homes can help reduce the vulnerability of communities to wildfires. Encouraging residents to create fire-resistant structures and maintain proper vegetation management can also aid in controlling fire spread.
- Collaboration and coordination: Successful wildfire control requires collaboration among multiple agencies, including fire departments, emergency services, land management agencies, and local authorities. Cooperation between these entities helps ensure effective resource sharing, information exchange, and coordinated response efforts.
- Research and technology**:** Advancements in wildfire modelling, remote sensing technologies, and fire behaviour prediction systems contribute to improved fire control strategies. Research on fire ecology, climate change impacts, fire-resistant materials, and fire-resistant planation also helps inform mitigation and control measures.

This literature review provides an overview of various strategies and policies for dealing with wildfires in different countries, including New Zealand, Australia, Canada, and the United States. It emphasises the importance of comprehensive measures to mitigate wildfire risks, such as integrated fire management, fuel management, community engagement, and proactive planning. The paper concludes by emphasising the significance of reducing carbon emissions, adapting to climate change, and implementing measures to minimise the social, economic, and ecological impacts of wildfires through effective management, collaboration, and community engagement.

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Appendix: List of major agencies that deal with wildfires

Australia

New South Wales Rural Fire Service (NSW RFS)

Queensland Fire and Emergency Services (QFES)

Western Australia Department of Fire and Emergency Services (DFES)

New South Wales National Parks and Wildlife Service

Queensland Parks and Wildlife Service

Western Australian Parks and Wildlife Service

Bureau of Meteorology (BOM): Provides weather forecasts and fire danger ratings

Commonwealth Scientific and Industrial Research Organisation (CSIRO)

Australasian Fire and Emergency Service Authorities Council (AFAC)

New Zealand

Fire and Emergency New Zealand (FENZ)

Department of Conservation (DOC)

United States

United States Forest Service (USFS)

Resources for Future (RFF)

National Interagency Fire Centre (NIFC)

National Centers for Environmental Information-National Oceanic and Atmospheric Administration (NOAA)

Canada

Canadian Interagency Forest Fire Centre (CIFFC)

Provincial and territorial wildfire management agencies (e.g., British Columbia Wildfire Service, Alberta Wildfire, Ontario Ministry of Natural Resources and Forestry)

United Nations

United Nations Environmental Program (UNEP) Spreading like Wildfire: The Rising Threat of Extraordinary Landscape Fires

Intergovernmental Panel on Climate Change (IPCC)