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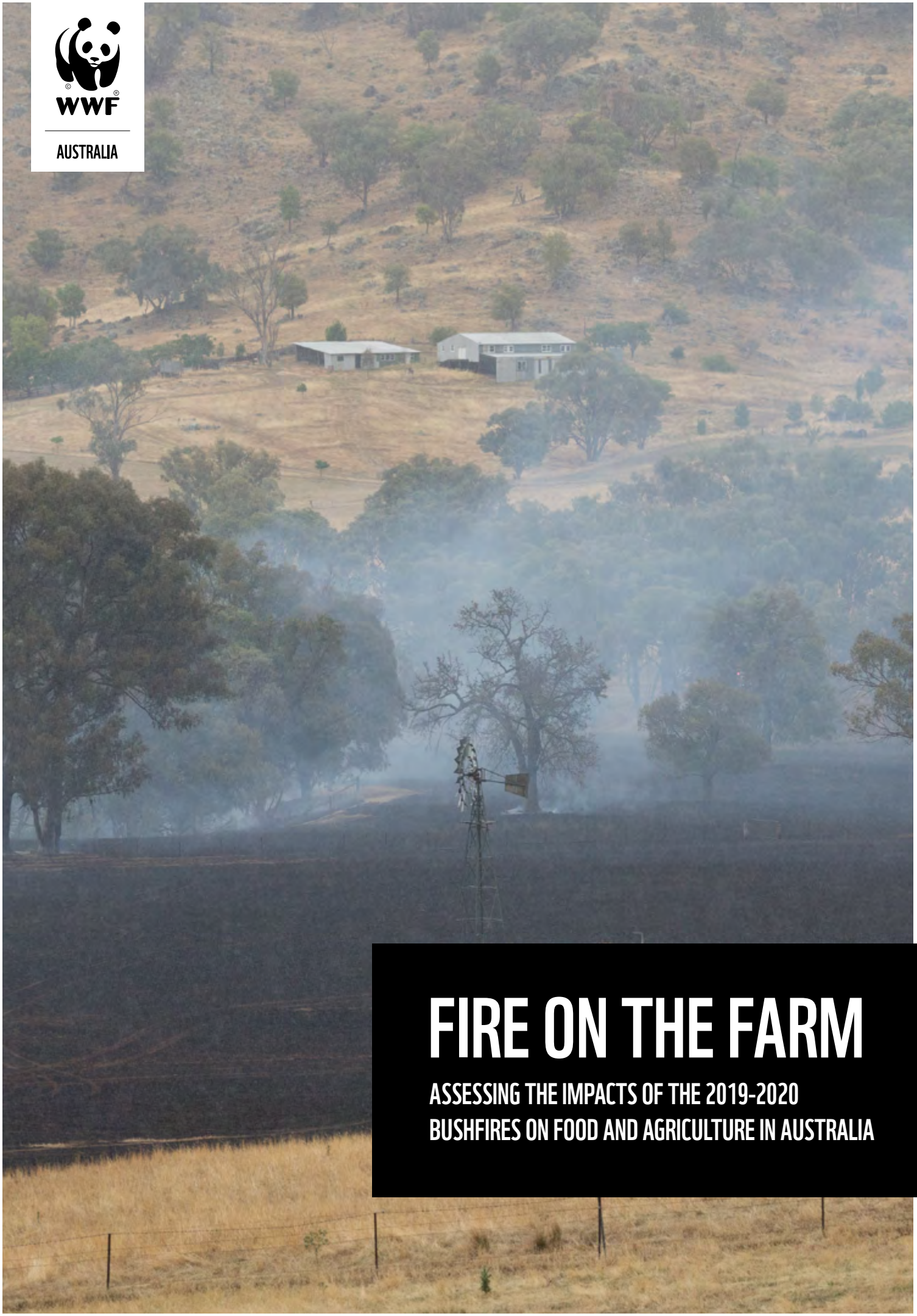

FIRE ON THE FARM

ASSESSING THE IMPACTS OF THE 2019-2020 BUSHFIRES ON FOOD AND AGRICULTURE IN AUSTRALIA

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SUMMARY

More than a year after the devastating bushfires of 2019-2020, Australia is still coming to terms with their impacts. Even in the shadow of the COVID-19 pandemic, the bushfires were a major milestone in Australia's history. As in other countries, bushfires in Australia are increasing in their extent, frequency, severity and duration, driven in part by climate change[1].

In addition to the tragic loss of lives, widespread smoke pollution and resulting human health problems, destruction of infrastructure and property, not to mention impacts on water and wildlife, the 2019-2020 bushfires in eastern and southern Australia also had significant effects on a range of major industries, including agriculture, forestry and tourism.

This report provides a review and synthesis of the economic impacts of the 2019-2020 bushfires on agriculture and the wider food system. Of the more than 10 million hectares burnt in south-eastern Australia during the 2019-2020 fire season (ABARES, 2021a), around one-quarter was agricultural land (Agri Investor, 2020). To assess this impact in economic terms, we investigated the effects of the bushfires on farmland values and food output, as well as non-market impacts on farm and food workers, consumer prices and other cross-sectoral effects. We also reviewed the value of bushfire recovery support to the food sector.

We estimate that the 2019-2020 bushfires caused at least $4-5 billion worth of economic losses to the Australian food system. This is equivalent to 6-8% of the value of national agricultural output in the same period (ABS, 2021a). Although not all bushfire impacts can be valued accurately in monetary terms, some examples include (in Australian dollars):

- $2-3bn worth of direct fire damage to farm property, infrastructure and land;
- Food production losses of around $2bn (including over 100,000 livestock deaths); and
- Health impacts on farmers and other food workers valued at over $279m.

There was also evidence of short-term increases in food prices and job losses in fire-affected areas, which added to the economic impact of the bushfires.

Insurance pay-outs and government assistance compensated for only part of these costs. We found that farmers and other food-related businesses received approximately 20% of economic recovery grants provided by governments in response to the 2019-2020 bushfires. Assuming a similar share of all bushfire recovery assistance, which was reported as totalling $8.2bn by the Royal Commission into National Natural Disaster Arrangements (2020a), we estimated total funding for bushfire recovery in food and agriculture of around $1.6bn.

From an environmental economic perspective, at least part of the decline in land values due to bushfires may be interpreted as a loss of *natural capital* (Organisation for Economic Co-operation and Development, OECD, 2001). Similarly, production losses due to bushfire damage represent a reduction in the *provisioning* ecosystem services (Food and Agriculture Organization of the United Nations, FAO, 2021) that ensure Australians and overseas customers are supplied with food. Human health impacts from exposure to bushfire smoke have been described as an ecosystem 'disservice' (Shackleton *et al.*, 2016)[2]. Bushfires may also undermine several *regulating* ecosystem services important for food production, such as tree cover that provides shelter for livestock, habitat for crop pollinators, or biological processes that maintain fertile soils[3]. In short, the 2019-2020 bushfires severely damaged the natural capital stocks and flows that underpin Australia's food system, with potential adverse impacts on food production for years to come.

It is a testament to the strength and resilience of farmers and the food system in Australia that they withstood the 2017-2019 drought, the 2019-2020 bushfires, and the COVID-19 pandemic. Despite these shocks occurring one after another, Australian food producers and distributors have continued to supply quality products to consumers both at home and abroad.

The long-term prospects for Australian food production are less clear. The devastating bushfires experienced in 2019-2020 may be considered as part of a pattern of increasingly severe natural catastrophes, alongside the preceding intense drought and subsequent heavy rainfall and flooding experienced in Australia during 2020-2021. More work is urgently needed to develop effective strategies to protect the food system in Australia, including adapting to expected increases in the risk of bushfires and other extreme weather events, while at the same time intensifying efforts to reduce emissions of greenhouse gases that exacerbate climate change. Governments should:

- Measure and monitor bushfire risks to, and impacts on, the food system;
- Strengthen insurance arrangements to cover the full costs of bushfires; and
- Assist food producers and related businesses to develop cost-effective bushfire risk mitigation and resilience plans.

Bushfire aftermath on a farm © Adobe stock / Stephen

1. INTRODUCTION: BUSHFIRES AND FOOD PRODUCERS

Bushfires have long played a critically important role in the Australian landscape. Some plant species depend on fire for reproduction. For thousands of years, fire was used by many Indigenous peoples to assist with food production (including hunting) and for ceremonial purposes. Today, fire services and land managers use preventative burns to protect lives and property, by reducing the risk of uncontrolled bushfires. In other words, fire can be helpful when it is well managed, although even prescribed burns can be problematic (Borchers Arriagada *et al.*, 2020a). The worst impacts typically occur when fires ignite unintentionally and burn out of control.

Australian farmers are on the frontline of bushfires. Their landholdings are often adjacent to forests, and fires may ignite on their own or neighbouring properties. Farm workers are more likely to suffer from the health effects of smoke pollution, due to their rural residence and long periods of outdoor work (Riden *et al.*, 2020). Farm workers and their family members are also more likely to be volunteers in local fire services, exposing them to the dangers of fighting bushfires[4].

Farmers have an important opportunity to reduce vulnerability to bushfires. One *direct* contribution is by managing land in ways that reduce the likelihood, intensity or spread of fire and resulting damages[5]. There is evidence from some countries that farmers can reduce fire risk while improving biodiversity and carbon sequestration outcomes (Pais *et a*l., 2020). The potential for similar 'win-win' outcomes in Australia is not known, although landholders can help *indirectly* by adopting land use practices that maintain and increase carbon stored in vegetation and soils (Wang *et al.*, 2020; Mosier *et al.*, 2021). If adopted at scale, such practices can help slow the pace of climate change and mitigate the rise in temperatures and increasing aridity, which is making bushfires more frequent and widespread (Collins *et al.*, 2021).

Other food producers affected by bushfires include businesses involved in harvesting wild foods (e.g., honey, game, native plants), as well as aquaculture operations, which can suffer from ash and sediment in run-off from fire-affected areas. The list of people whose activities were disrupted by the 2019-2020 bushfire also includes farm suppliers, food processors, distributors, and wholesale and commercial retailers. Any attempt to assess the impacts of bushfires on the food system must therefore consider a range of different industries and supply chains.

2. HOW DO BUSHFIRES AFFECT THE FOOD SYSTEM?

The impacts of bushfires are complex. They include direct and indirect, tangible and intangible, short-term and long-term consequences across social, economic and environmental dimensions (Stephenson, 2010; Deloitte Access Economics, 2016; Thomas *et al.*, 2017).

The direct, tangible and immediate impacts of bushfires on the food system may include the death or injury of production workers, as well as smoke inhalation and other injuries sustained while responding to or fleeing fires. Direct impacts also include the loss of crops, livestock or harvested products, and damage to buildings, infrastructure and equipment related to the production, processing, storage and transport of food.

The indirect, intangible or long-term impacts of bushfires are more difficult to assess but include:

- Mental health impacts on food workers and other affected populations;
- Higher transport costs for inputs and/or outputs, due to road closures in affected areas (Transport for NSW, 2020);
- Reduced availability of certain food products, which may lead to consumer price increases;
- Changes in land valuations and/or insurance premiums against the risk of future bushfires;
- Reduced activity in rural industries (e.g., hospitality and tourism) that provide an important source of off-farm income;
- Polluted run-off from bushfire-affected areas, which contaminates water supplies (Bladen *et al.*, 2014), including water used by downstream food producers such as shellfish aquaculture (Boys, 2020); and
- Greenhouse gas (GHG) emissions, which threaten the food system more generally (Box 1).

Bushfire Aftermath © Adobe stock / Stephen

BOX 1. CLIMATE IMPACTS OF THE 2019-2020 BUSHFIRES

In 2020, WWF published a report on the value of natural capital losses due to the 2019-2020 bushfires, focusing on the costs and benefits of mitigating greenhouse gas (GHG) emissions (Bishop, 2020). The valuations provided were based on early estimates of GHG emissions from the bushfires, which ranged from 400-700 million tonnes of CO_2 equivalent (Mt CO_2-e). Bishop assumed that 90-95% of GHG emissions from bushfires would be re-sequestered over time through natural regrowth of vegetation (see Annex 1), resulting in net GHG emissions of between 20 and 70 Mt CO_2-e after 10 years. Bishop valued the global damages from the 2019-2020 bushfire emissions at $1.54-5.39bn, based on an independent estimate of the Social Cost of Carbon (National Academies of Sciences, Engineering, and Medicine, 2017).

Bishop further estimated that an investment of $0.30-1.05bn in forest restoration or other carbon offsets would be sufficient to mitigate this global economic damage, depending on the volume of residual GHG emissions and the market price of carbon credits. In terms of GHG alone, the analysis suggested that compensating for residual bushfire emissions was a worthwhile investment. It should be noted that this valuation did not include the many co-benefits that can result from protecting or regenerating forests, increasing soil carbon stocks, or other practices used to offset GHG emissions.

In April 2020, the Australian Government released updated estimates of GHG emissions from the 2019-2020 bushfires across 7.4 million ha of temperate forests (Department of Industry, Science, Energy and Resources, DISER, 2020a). Emissions from bushfires in these areas were reported to be 830-940 Mt CO_2-e, exceeding the 'worst case' estimates used in the earlier analysis by Bishop (2020). Using these new estimates of GHG emissions, and assuming again that 90-95% of emissions are re-sequestered within 10 years, we re-calculated the total economic damages as $3.21-7.27bn from bushfire emissions in 2019-2020. Potential mitigation costs increased proportionately, to $0.65-1.48bn. The case for mitigation remains strong, with a return on investment of 2:1 or better. Further details of the valuation are provided in Annex 2.

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3. ASSESSING BUSHFIRE IMPACTS ON THE FOOD SYSTEM

In the discussion that follows we review evidence of the impacts of the 2019-2020 bushfires on food and agriculture. We focus on the regions of eastern and southern Australia where fire impacts were most severe[6]. We evaluate bushfire impacts in terms of:

- Damage to farm property and land (asset values);
- Food production losses (current revenues);
- Health impacts on farmers and food workers (human capital); and
- Consumer price changes and other market impacts.

The distinction between damage to stocks (i.e., assets and human capital) and flows (revenues) is important due to the longevity of the resulting impacts. Damage to an asset implies a reduction in the benefits (flows) derived from that asset during its lifetime. Bushfires can destroy or damage a range of productive assets, including buildings and infrastructure, machinery, and equipment (also known as 'built' or 'produced' capital), as well as forests, soils and wildlife ('natural capital'). In contrast, damage to current production (e.g., annual crops) may be considered a one-time loss, provided the assets upon which such production depends remain intact.

Key sources of information considered for this report include:

- Official government inquiries into the 2019-2020 bushfires (Box 2);
- Government data and reports on the agriculture sector, especially the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES)[7];
- Peer-reviewed literature, reports or summaries via outlets such as *The Conversation*[8];
- Private industry data services, e.g., IBISWorld[9], Agri Investor[10]; and
- General news and other public media coverage.

In addition to the sources listed above, this report draws on an unpublished dissertation by Chuan Huang of the University of Sydney, entitled *The 2019-2020 Bushfire Impacts on Food in Australia* (Huang, 2020). Huang's report is available on request.

BOX 2. GOVERNMENT INQUIRIES INTO THE 2019-2020 BUSHFIRES

Some data on the impacts of the 2019-2020 bushfires is available in official reports from government inquiries. These include the Royal Commission into National Natural Disaster Arrangements (Royal Commission, 2020a), as well as state-level inquiries in New South Wales (NSW Government, 2020), South Australia (Government of South Australia, 2020) and Victoria (State of Victoria, 2020). Limited information on bushfire impacts is provided in these reports, which focus more on issues relating to bushfire preparation, prevention and management. With respect to bushfire impacts, in particular:

- The report of the Royal Commission into National Natural Disaster Arrangements, which was developed in response to the 2019-2020 bushfires, contains extensive evidence but does not provide a systematic inventory of bushfire impacts. Neither does the report attempt to disaggregate the impacts of bushfires on different regions, industries or segments of the community. Some detail is provided for health impacts and damage to ecosystems and wildlife, but these are exceptions.
- The NSW inquiry focused on understanding why the 2019-2020 fires were so destructive and made several recommendations for improving bushfire prevention and management. The inquiry did not dwell on the impact of bushfires but includes a one-page 'infographic' that describes some of the main losses (Fig. 0-1, pg. xxi).
- The inquiry held in South Australia also focused on planning, preparation, response and recovery, rather than impact assessment. The South Australian report includes an 'infographic' showing bushfire losses (Fig. 1, pg. iii). The report notes that Kangaroo Island was particularly badly affected (e.g., "*stock losses were extreme, devastating the local agriculture sector*").
- The Victorian Fire Season inquiry was conducted in two stages. Phase 1 focused on preparations for and responses to the 2019-2020 fire season and a report released in July 2020 included some data on bushfire impacts. Phase 2 focused on bushfire relief and recovery arrangements[11].

Table 1 provides a selection of bushfire impact data derived from state-level inquiry reports from NSW, South Australia and Victoria, focusing on *food-related* property losses.

NEW SOUTH WALES	SOUTH AUSTRALIA	VICTORIA
• 601,858 ha of pasture burnt • 88,832 linear km of agricultural boundary fencing damaged	• 172,591 ha of private land burnt (two-thirds of it on Kangaroo Island) • 1,190 primary production businesses impacted • $186.6m in agricultural production losses • 67,928 livestock killed (worth $17m), of which 59,730 were on Kangaroo Island • 781 ha viticulture burnt, worth $8.8m	• 52,022 ha pasture burnt, including 15,000 ha in East Gippsland and 28,873 ha in north-eastern (NE) Victoria • 478 agricultural buildings damaged • 4,388 livestock killed, of which 3,800 were in NE Victoria • 18,493 tonnes of hay and silage and 700 ha of field crops destroyed in NE Victoria

Table 1. Food-related property losses due to bushfires in NSW, South Australia and Victoria.


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4. PROPERTY LOSSES DUE TO THE 2019-2020 BUSHFIRES

Information on bushfire damage to buildings, infrastructure, machinery and equipment and other tangible assets is available from multiple sources, including government agencies[12], industry peak bodies, businesses and the general media. An indication of the magnitude of insured losses was published by the Insurance Council of Australia (ICA) in August 2020. The ICA reported 38,416 insurance claims for $2.33bn worth of losses from the 2019-2020 bushfires in the states of Victoria, NSW, South Australia and Queensland (ICA, 2020a). This included 9,389 home building claims, 14,237 building contents claims, 2,945 motor vehicle claims, 8,738 commercial property claims and 1,285 business interruption claims.

The ICA does not provide a breakdown of insurance claims by industry. However, an estimate can be derived from a submission by the ICA to the Royal Commission, which notes that 'commercial' claims accounted for 28% of the total (ICA, 2020b). On this basis, we have inferred that total insurance claims by food producers for bushfire damage to business assets (as opposed to personal property) did not exceed 28% of all claims (i.e., no more than $650m). This includes fire damage to farm equipment, sheds, fencing and farm tracks, as well as loss of livestock, crops and/or plantations. It should be noted that the 28% figure includes claims by businesses in *non-food* related industries (e.g., tourism and forestry). This implies in turn that settled claims submitted by food producers amounted to less than $650m[13].

38,416

INSURANCE CLAIMS FOR $2.33BN WORTH OF LOSSES

5. REDUCTION IN LAND VALUES FOLLOWING BUSHFIRES

In addition to damaging buildings and infrastructure, intense bushfires may affect the productivity and market value of the land on which these assets are located, as well as other natural assets that support food production (e.g., forests). Some measurements of the impacts of bushfires on natural capital are available (State of NSW, 2021; Ward *et al.*, 2020), although determining prices to value these impacts in monetary terms is difficult. This section focuses on bushfire impacts on the value of farmland – a fundamental input to production for which quantitative data and prices are available.

Bushfires can result in accelerated soil loss and degradation, particularly in steep terrain, where the recovery of vegetated ground cover is slow[14]. On the other hand, ash from vegetation burnt in bushfires contains nutrients that can improve soil fertility (Santin and Doerr, 2016) or enhance carbon storage (Jenkins *et al.*, 2014). In other words, the effects of fire on soil are complex and heterogeneous across the landscape.

Aftermath of the bushfires © Adobe stock / Daniela Photography

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One recent review explains how intense bushfires, like those experienced in southern and eastern Australia in 2019-2020, can lead to lasting and potentially irreversible soil degradation (Australian Academy of Science, 2020). The authors note that, while crop nutrient availability may increase after bushfires, this does not always offset the degradation of soil structure which may have significant long-term adverse effects on nutrient availability.

In principle, we would expect a change in soil quality to affect the market value of farmland. A recent review by the agency responsible for valuing land for taxation purposes in NSW (Valuer General NSW, 2020) found no research specific to the impact of bushfires on land values but ample evidence that *"the value impact of a bushfire is generally negative on property values"*.

The Valuer General NSW estimated the impact of the 2019-2020 bushfires on land values in NSW based on case studies of market value changes after previous major bushfire events. The report documented evidence of reductions in land value because of bushfires in three out of four case study locations. Importantly, the Valuer General NSW distinguished the impacts of bushfire on the value of residential property (dwellings) from impacts on the value of the land, finding *"a faster return to functional effectiveness for the house market than for the land market"*. The Valuer General NSW suggested this mainly reflected excess supply of vacant land for sale in the aftermath of major bushfires. Land buyers may also be aware of physical changes in soil quality due to bushfires or may respond adversely to the poor aesthetic qualities of a burnt landscape.

The Valuer General NSW concluded that the decline in rural land values between July 2019 (pre-fire) and July 2020 (post-fire) was as great as 30%, where more than half of all properties were destroyed and where the prevailing demand for vacant land was low. At the other end of the scale, the Valuer General NSW suggested there would be no decline in land value following bushfires in locations where the proportion of properties destroyed was below 25% and the demand for vacant land was high. In other words, changes in the market value of land reflect not only changes in its inherent physical characteristics and productivity due to fires but also local trends in supply and demand[15].

INTENSE BUSHFIRES, LIKE THOSE EXPERIENCED IN SOUTHERN AND EASTERN AUSTRALIA IN 2019-2020, CAN LEAD TO LASTING AND POTENTIALLY IRREVERSIBLE SOIL DEGRADATION.

6. EXTRAPOLATING BUSHFIRE IMPACTS ON LAND VALUE

Estimates of a decline in land values due to the 2019-2020 bushfires, as described in the report from the Valuer General NSW, can be applied to the average value of farmland in affected regions and multiplied by the area of burnt farmland to calculate the total loss of agricultural land value.

Huang (2020) used this approach by overlaying maps of current land use (ABARES, 2019a) and fire extent (Department of Agriculture, Water and the Environment, DAWE, 2020)[16] with a map of broadacre farmland prices provided in Chancellor *et al.* (2019). This allowed Huang to estimate the average price of farmland in burnt areas, which he then multiplied by the percentage decline in land value due to bushfires (Valuer General NSW, 2020) and the total area of agricultural land damaged by bushfires in each Australian state, using data from Agri Investor (2020) and other sources[17]. Further details on Chancellor *et al.* (2019) and Huang's approach are provided in Annex 3.

Huang's estimate of the mean value of burnt farmland was A$7,109/ha, which is higher than the average value of all broadacre farmland reported by Chancellor *et al.*[18] This may reflect the fact that the areas of southern and eastern Australia most affected by the 2019-2020 bushfires were in higher rainfall regions and closer to markets and were, on average, worth more. Similarly, the median price of all Australian farmland in 2020, as reported by the Rural Bank (2021), was $5,907/ha but median values were higher in those regions worst affected by the 2019-2020 bushfires (e.g., south-east NSW (median $7,390/ha), Gippsland ($10,450/ha) and the Adelaide and Fleurieu region of South Australia ($14,253/ha)).

The total area of burnt agricultural land reported in Huang (2020) was 2.628 m ha[19], or slightly less than 1% of all agricultural land in Australia (384 m ha). To put this into context, ABARES separately reported that, as of 28 April 2020, the total fire extent in southern and eastern Australia was 10.3 m ha, of which 8.5 m ha was forest (mostly native species on public land) (ABARES, 2021a). This means that approximately one-quarter of the area affected by bushfires in 2019-2020 was agricultural land.

On this basis, Huang calculated total agricultural land value losses due to the 2019-2020 bushfires ranging from $1.7bn (assuming a 10% reduction in agricultural land value) up to $5.1bn in the worst-case scenario (30% reduction in land value). An intermediate estimate, assuming a 20% average reduction in agricultural land value due to bushfires, was $3.4bn. The latter figure is equivalent to $1,300/ha burnt on average.

The estimates reported by Huang are based on the top-of-the-range price per hectare of farmland in burnt areas, based on the map of land values in Chancellor *et al.* (2019)[20]. For a more conservative analysis, we used mid-range land prices[21]. Our estimates of land value loss are therefore lower than reported by Huang but still substantial, ranging from $1.18 to $3.55bn, with a mid-range estimate of $2.36bn ($900/ha on average), assuming a 20% loss in value due to bushfires. The largest estimated losses were in Queensland, where average agricultural land values are relatively low but the area affected by bushfires was greatest. The second largest impact on land value was in NSW (Table 2).


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Bushfire aftermath © Adobe stock Stephen

	QLD	NSW	VIC	WA	SA	ACT	TAS	TOTAL
AREA BURNT (HA)	1,633,000	559,000	163,000	170,000	99,000	3,000	800	2,628,000
AVERAGE PRE-FIRE VALUE ($/HA)	3,867	5,941	5,828	4,737	4,050	7,500	5,250	4,497
LAND VALUE LOSS ($ MILLION)								
10% LOSS	631.5	332.0	94.9	80.5	40.1	2.3	0.4	1,181.8
20% LOSS	1,263.0	664.0	189.9	161.1	80.2	4.5	0.8	2,363.5
30% LOSS	1,894.4	996.1	284.9	241.6	120.2	6.8	1.3	3,545.3

Table 2. Agricultural land value losses due to the 2019-2020 bushfires by state or territory.
Source: Adapted from Huang (2020).

To put these losses in context, the Australian Bureau of Statistics (ABS) estimated the net value of the capital stock employed in the agriculture, forestry and fishing industries at $145.7bn, in current prices, as of June 2020 (ABS, 2020a). The ABS also estimated the total value of rural land in NSW (including 'hobby farms and residential rural land') at $174bn in June 2020 (ABS, 2020b). In short, the impact of bushfires on farmland values is modest relative to the total value of assets devoted to food production in Australia.

For most landholders in bushfire-affected areas, the impact of fires on underlying land values may represent temporary 'paper losses' rather than a realised loss of wealth, unless they wanted to sell their property or borrow against the capital value in the immediate aftermath of the fires. On the other hand, if the events of 2019-2020 cause people to revise their perceptions of future bushfire risk, land values may have been permanently depressed.

Based on this analysis, we conclude that the value of property losses for bushfire-affected food producers, including damage to buildings, equipment and infrastructure, along with potential decline in the market value of agricultural land, falls in the range of $2-3bn.

7. FOOD PRODUCTION LOSSES DUE TO BUSHFIRES

The preceding sections focused on valuing bushfire impacts on food system assets, as revealed by insurance claims and estimated changes in the value of broadacre farmland. Another way to assess the impact of bushfires on food and agriculture is to look at changes in current production and/or revenue, particularly the reduced output of livestock[23] and crops due to fire damage.

Early reports of the impacts of the 2019-2020 bushfires on food production emerged while the fires were still burning[24]. The extent of damage became clearer with the publication of data in January 2020 and again in March 2020 on the area of farmland affected by fire (Agri Investor, 2020)[25]. Additional information for agricultural production losses is available in state-level bushfire inquiry reports (Box 2), although South Australia was the only state to report monetary estimates of the damages ($186.6m in production losses).

At a broader scale, a preliminary estimate of the national economic impact of the 2019-2020 bushfires was provided by IBISWorld (2020), with reported agricultural losses of as much as $4.1bn. This includes forecast reductions in farm revenue across livestock, viticulture and fruit and vegetable producers totalling $1.98bn (Table 3).

In the horticulture industry, for example, some of the main fresh produce growing regions in South Australia, Victoria and NSW were either burnt or affected by smoke[26]. Revenue losses in wine, fruit, and vegetable growing were estimated by IBISWorld at $629m (Table 3).

For the meat and dairy industries, IBISWorld reported that the 2019-2020 bushfires affected regions of eastern Australia hosting around 20% of the national cattle herd and 30% of sheep. As of March 2020, total livestock deaths were reported to exceed 100,000 animals[27]. Moreover, due to power outages and road blockages during the fires, IBISWorld reported that over 800,000 litres of milk was wasted, which Huang (2020) valued at $400,000 using 2019-2020 farm-gate dairy prices[28].

IBISWorld does not explain the methods used to generate its estimates of bushfire impacts. However, as a way of validating the numbers provided, we can estimate production losses by multiplying the total area of farmland affected by bushfires by the average annual value of production on agricultural land (Box 3). This suggests that the aggregate estimates provided by IBISWorld are plausible, even if losses may be higher or lower for specific industries.

INDUSTRY	ESTIMATED REVENUE IN 2019-2020 ($ MILLION)			CHANGE (%)
	BEFORE BUSHFIRES	AFTER BUSHFIRES	CHANGE	
UNDER-COVER VEGETABLE GROWING	757.7	702.0	55.7	-7.4
OUTDOOR VEGETABLE GROWING	4,313.1	3,996.1	317.0	-7.3
APPLE, PEAR AND STONE FRUIT GROWING	954.1	928.6	25.5	-2.7
GRAPE GROWING	1,559.8	1,438.8	121.0	-7.8
CITRUS FRUIT, NUT AND OTHER FRUIT GROWING	4,119.8	4,009.7	110.1	-2.7
SHEEP FARMING	4,561.1	4,317.9	243.2	-5.3
BEEF CATTLE FARMING	16,623.8	16,250.6	373.2	-2.2
BEEF CATTLE FEEDLOTS	4,676.5	4,571.5	105.0	-2.2
SHEEP-BEEF CATTLE FARMING	6,184.2	5,998.0	186.2	-3.0
GRAIN-SHEEP OR GRAIN-BEEF CATTLE FARMING	11,595.3	11,246.1	349.2	-3.0
DAIRY CATTLE FARMING	4,427.1	4,330.2	96.9	-2.2
TOTAL	59,772.5	57,789.5	1,983.0	-3.3

Table 3. Australian agricultural revenue, before and after bushfires.
Source: IBISWorld (2020).

BOX 3. ESTIMATING THE VALUE OF AGRICULTURAL PRODUCTION LOSSES FROM THE 2019-2020 BUSHFIRES

The gross market value of crop and livestock production across Australia in 2019-2020 was reported as $60,664m, including $28,337m for crops and $32,327m for livestock (ABARES, 2019b). These numbers are comparable to production values reported by IBISWorld (2020) in Table 3.

The total area of land used to produce this output was 373 m ha, according to the Australian Bureau of Statistics, of which 31 m ha was classified as crops, 36 m ha 'improved pasture' and 305 m ha 'other grazing land' (ABS, 2018). Based on these figures, and supplementary data from ABARES (2019b), we estimated the average value of production per hectare in 2019-2020 (Table 4).

DESCRIPTION	ALL AGRICULTURE	ALL CROPS	GRAINS, OILSEEDS AND PULSES	ALL LIVESTOCK	IMPROVED PASTURE
GROSS VALUE OF PRODUCTION ($MILLION)	60,664	28,337	NA	32,327	NA
PRODUCTION AREA ('000 HA)	372,721	31,074	18,584	340,763	35,567
ESTIMATED RETURN ($/HA/YR)	163	912	1,524*	95	909*

Table 4. Agricultural production value, area and average returns per hectare.

* Estimated returns for 'grains, oilseeds and pulses' are overstated, as they include the value of crops grown outside the stated production area. Similarly, estimated returns for livestock on 'improved pasture' includes the value of livestock raised on 'other grazing land'. These are considered high estimates. 'NA' denotes that relevant data was unavailable.

Sources:

- ABARES (2019b) for gross production value and area devoted to 'grains, oilseeds and pulses'; and
- ABS (2018) for agricultural land use in 2016-2017.

Agri Investor (2020) did not provide a breakdown of the types of agricultural land affected by bushfires. However, we assume their final estimate of 2.46 m ha (based on analysis by Digital Agriculture Services) includes a mix of cropland, improved pasture and other grazing land. If we add the estimate of damaged farmland in the ACT (3,000 ha) and WA (170,000 ha) reported by Huang (2020), we can simply multiply the average value of agricultural production in Table 4 ($163/ha/yr) by the total area of bushfire-affected land (2.628 m ha) to derive a minimum estimate of total production losses in 2019-2020 of $428m.

This figure probably understates the true value of agricultural production losses. Arguably the category 'other grazing land' should be excluded from the land base when calculating average returns in bushfire-affected areas. The most extensive grazing lands are found in arid zones of central and Western Australia, which were relatively unscathed by the 2019-2020 bushfires.

If we exclude 'other grazing land', we obtain higher estimates of average production value of $912/ha/yr for crop land and $909/ha/yr for livestock production on 'improved pasture' (Table 4). These estimates are more consistent with the spatial distribution of agricultural profits in Australia (Marinoni *et al.*, 2012), as well as the farmland value maps in Chancellor *et al.* (2019).

If we apply the mean of these values ($910/ha/yr) to the total area affected by bushfires (2.628 m ha), we obtain an estimate of $2.39bn in agricultural production losses due to the 2019-2020 bushfires. This may be an overestimate, given that some livestock production value comes from 'other grazing land', fire-affected crops may have some salvage value, and some livestock in areas affected by the bushfires may have been rescued or otherwise unharmed.

Based on this simple analysis, total agricultural production losses due to the 2019-2020 bushfires would lie in the range of $428m to $2.39bn, with the true value probably closer to the higher estimate. This is comparable to the estimated $1.98bn loss in production reported by IBISWorld (shown in Table 3). Note that losses experienced by other food producers, processors and distributors due to the bushfires are additional to those shown in Table 3, which may explain the larger headline figure of $4.1bn reported by IBISWorld (2020).


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Notwithstanding the substantial impacts of the 2019-2020 bushfires on food production in affected regions, at a national scale the effect was not obvious. Crop reports by ABARES covering the period from 1 April 2019 to 31 March 2020 showed a decline in both winter and summer crop production, when forecasts from September 2019 (ABARES, 2019c) are compared to post-harvest estimates released one year later (ABARES, 2020a).

The difference was most dramatic in the case of NSW, with a 35% gap between forecast and actual winter crop production, and in Western Australia, with a 19% gap. ABARES ascribes these shortfalls to unfavourable growing conditions, including below-average rainfall and above-average daytime temperatures, rather than to the bushfires[29]. This is not entirely surprising, given that a relatively small proportion of Australia's farms were affected by bushfires, as well as the extensive drought conditions experienced during the preceding two years (ABARES, 2020b).

Based on available data, we estimated that total production losses experienced by bushfire-affected food producers, including livestock and crops, amounted to approximately $2bn. Losses were concentrated in fire-affected regions and came on top of the impact of an extended drought.

Suburb in a smoke haze from bushfires © Adobe stock /Daria Nipot

8. HEALTH IMPACTS ON FARMERS AND FOOD WORKERS

Alongside impacts on tangible wealth and business income, food producers were also directly affected by physical and emotional injuries resulting from the bushfires. These impacts are more difficult to measure but no less real (Box 4).

We found no systematic assessment of the impacts of the 2019-2020 bushfires specifically on the physical or mental health of farmers or food producers. We therefore used population-level estimates of health-related damages and adjusted them according to the number of workers in the food system. This approach was adopted by Huang (2020), based on the assumption that food workers suffered at least as much health impact from bushfires as other social groups.

It is well known that smoke from bushfires can lead to increased respiratory complaints, as well as adverse cardiovascular events (Vardoulakis *et al.*, 2020). Moreover, there is evidence that the particulate matter in bushfire smoke can be several times more harmful to human health than particulate matter from other sources, such as vehicle exhaust (Aguilera *et al.*, 2021).

One study estimated that smoke from the 2019-2020 Australian bushfires – measured as an increase in the concentration of particulate matter – led to increases of 5.6% in all-cause mortality, 4.5% in cardiovascular mortality and 6.1% in respiratory mortality (Yu *et al.*, 2020). Moreover, the rates of hospitalisation and emergency department visits due to respiratory diseases and chronic obstructive pulmonary diseases tend to increase with exposure to bushfire smoke. Pregnant women, children and elderly people are especially vulnerable (Vardoulakis *et al.*, 2020).

A widely cited analysis of the impacts of bushfire smoke on health by Johnston *et al.* (2021) suggested that the 2019-2020 bushfires may have led to increased premature mortality, as well as higher hospital admissions for cardiovascular and respiratory diseases, and increased emergency attendances for asthma. Johnston *et al.* estimated the total costs of these health impacts at nearly $1.95bn (Box 5).

BOX 4. ASSESSING THE INTANGIBLE COSTS OF BUSHFIRES AND OTHER NATURAL DISASTERS

In a series of reports to the Australian Business Roundtable for Disaster Resilience and Safer Communities, Deloitte Access Economics (Deloitte) assessed the tangible and intangible costs of floods, cyclones and other natural disasters in Australia[30].

As part of this work, Deloitte assessed the economic impacts of the 2009 bushfires in Victoria. It found that insured losses ($1.27bn in 2011 dollars) amounted to about half of all tangible costs ($2.64bn in 2011 dollars) (Deloitte, 2016). In other words, only half of all tangible bushfire losses were covered by insurance. Adjusting for inflation, Deloitte reported total tangible costs of $3.1bn (expressed in 2015 dollars)[31].

Deloitte treated intangible costs as a separate impact category. This included the economic consequences of fatalities as well as non-fatal physical injuries and disability, mental health impacts, increased incidence of family violence, chronic disease, alcohol and drug misuse, and certain environmental impacts. Deloitte's estimate of the intangible cost of the bushfires in Victoria in 2009 was $3.9bn (expressed in 2015 dollars), of which $410m was attributed to environmental impact.

Based on their analysis, Deloitte concluded that the ratio of total economic costs, including both tangible and intangible costs, to insured losses was approximately 4.9 to 1 for bushfires in Australia (Deloitte, 2017)[32]. If this ratio is applied to the total pay-out of $2.33bn for insured losses in the 2019-2020 bushfires (ICA, 2020a), we obtain an estimate of total economic costs of around $11.4bn across all sectors, including food.

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BOX 5. ESTIMATING THE HEALTH IMPACTS AND COSTS OF BUSHFIRE SMOKE

Johnston *et al.* (2021) estimated population-level exposure to bushfire smoke (PM_{10} and $PM_{2.5}$) during the period 1 October 2019 to 31 March 2020. To do this, air quality monitoring data was obtained for all forested regions (excluding the northern tropical savannahs), where over 80% of Australians live. The authors combined this data with previously published analyses and official guidance on the health risks of air pollution to derive estimates of bushfire health impacts, which they valued in economic terms.

Johnston *et al.* (2021) estimated that the 2019-2020 bushfires resulted in 429 premature deaths (with a 95% confidence interval from 154-712 deaths), 3,230 additional hospital admissions for cardiovascular and/or respiratory diseases, and 1,523 additional emergency attendances for asthma. Comparable estimates are presented in an article by some of the same authors (Borchers Arriagada *et al.*, 2020b). The estimated health impacts reported by Johnston *et al.* (2021) were corroborated with clinical data, which showed elevated hospital presentations for respiratory complaints during the bushfire season in NSW, as well as increased pharmaceutical sales and dispensing of treatments for respiratory complaints in the ACT, NSW and Victoria (Australian Institute of Health and Welfare, 2020).

Johnston *et al.* (2021) used various methods to value selected health impacts. Premature mortality was assessed using the value of a 'statistical life' ($4.5m per person, on average, in 2014)[33]. Hospitalisations and emergency department presentations were valued using average clinical costs from official hospital pricing data. Productivity impacts were measured in terms of lost income by adults of working age during a typical hospital stay and using the average daily salary in Australia. All costs were expressed in 2018 dollars. On this basis, the authors estimated total health costs at $1.95bn, with a 95% confidence interval of $695m to $3.25bn. The authors asserted that this exceeds the total health costs caused by all fire events in Australia during the previous 5 years.

Premature mortality, alone, accounted for almost 99% of the total health cost estimated by Johnston *et al.* (2021). The authors note that NSW suffered the highest health cost among all states, at $1.07bn, followed by Victoria and Queensland, at $493m and $224m, respectively. The authors emphasised that their estimates were conservative and did not include many other health impacts, including reduced labour productivity and mental health effects, and therefore understated the full health burden of bushfires.

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The immediate question for this report is what portion of total health impacts and costs due to the 2019-2020 bushfires were borne by people involved in the food system. We would expect farm workers to be more exposed to the risks of bushfire smoke, given their involvement in physically demanding work that is largely conducted outdoors (Riden *et al.*, 2020).

In the absence of data for the number of food workers exposed to smoke during the 2019-2020 bushfire season and their relative vulnerability, Huang (2020) assumed that the health costs borne by farm workers were proportional to the share of farm workers in the total Australian population. He calculated the value of bushfire smoke impacts on the health of farm workers by taking the estimated national health cost reported by Johnston *et al.* (2021) – $1.95bn – and multiplying this by the proportion of the Australian population involved in farm work (i.e. 228,372 out of 25,649,985 or 0.89%). The resulting estimate of health costs was about $17m.

An alternative approach is to compare the number of agricultural workers to overall employment, rather than to the national population. In other words, the total health cost of $1.95bn can be divided by national employment to derive an average health cost per worker. This approach assumes that farm workers and non-farm workers have similar size households and similar dependency ratios (e.g., number of children, full-time students, employed or retired persons per worker), which may not be the case. However, this approach may reflect more accurately the relative share of smoke impacts incurred by all people who reside with farm workers.

The ABS reported a total of 13.06 m employed persons in February 2020, of which 291,500 were employed in the agriculture sector (ABS, 2020c). This was just before the job losses resulting from the COVID-19 pandemic. Employment in agriculture was about 2.2% of total employment.

If agricultural workers and their families have similar exposure and vulnerability to bushfire smoke as employees and their families in other industries – a conservative assumption – we can infer that farm workers and their families bore approximately 2.2% of the health cost calculated by Johnston *et al.* (2021), or about $43.5m[35].

The same calculation can be applied to other workers in the food system, including those involved in support services to agriculture, food transport, manufacturing and distribution. While we did not find data on employment in all food-related industries, the ABS provided data for some relevant industries, showing a total of 1.58 m persons employed in February 2020[36].

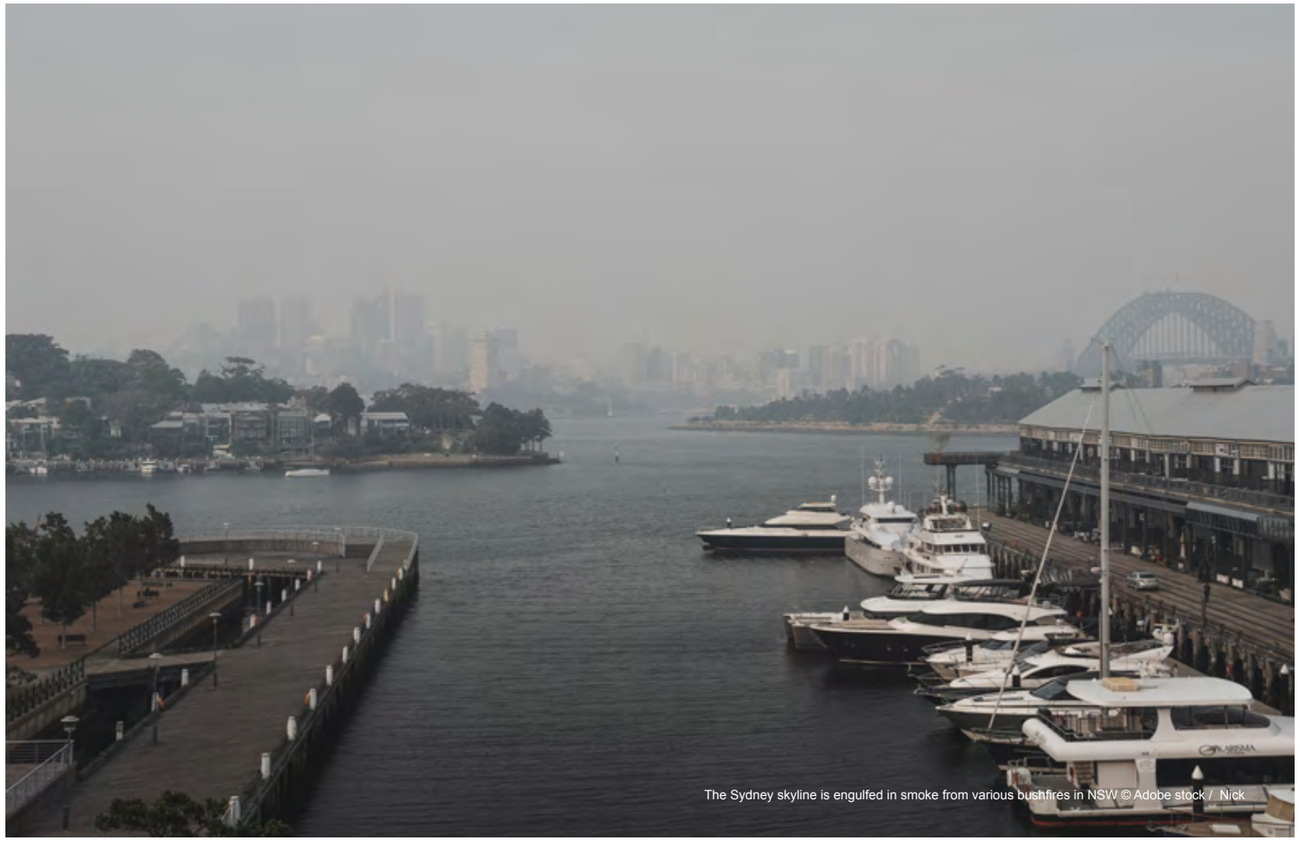
Assuming these workers (and their families) had similar exposure and vulnerability to the health effects of bushfire smoke, and again using the overall cost estimates reported by Johnston *et al.* (2021), we obtained a total of $236m in health costs borne by the employees of downstream food-related industries (and their families).

The above estimates exclude other health costs of bushfires, including impacts on mental health, which are significant (Deloitte Access Economics, 2013; Australian Institute of Health and Welfare, 2020). For example, a survey of 3,000 Australians conducted in early 2020 revealed that over half of the participants experienced some form of anxiety or worry because of the bushfires, with women and young people showing a higher degree of impact than other participants (Biddle *et al.*, 2020).

Research suggests that mental health impacts from natural disasters can be slow to emerge and long-lasting (Table 5). It may still be too soon to assess the full impact of the 2019-2020 bushfires on the mental health of Australians, including food workers and their families.

FIRE EVENT	TOPIC	FINDING	SOURCE
1983 'Ash Wednesday' bushfires	Prevalence of mental health problems after a major bushfire	"Twelve months after the fires, 42% (n = 1,526) of victims were defined as a potential psychiatric case … a significantly greater level of morbidity than found in communities that have not experienced a natural disaster."	McFarlane *et al.* (1997)
2003 bushfires in Canberra	Experiences of people directly affected by the fires [and] … the longer-term recovery experience	"Three years after the bushfire, approximately one-third of respondents (39%) perceived lasting negative consequences for their day-to-day life."	Camilleri *et al.* (2010)
2009 bushfires in Victoria	Prevalence and predictors of psychological outcomes in affected communities after 3-4 years	"A significant minority of people in the high-affected communities reported persistent PTSD [Post-traumatic stress disorder], depression, and psychological distress."	Bryant *et al.* (2014)
2009 bushfires in Victoria	Life satisfaction, mental health disorders, anger and violence against women, and community cohesion after 3, 5 and 10 years	"Ten years after the fires, 22% of people were reporting symptoms consistent with a diagnosable mental health disorder, including post-traumatic stress disorder, depression and psychological distress — more than twice the levels in low-impacted communities."	Gibbs *et al.* (2021)

Table 5. Mental health effects of bushfires: Australian case studies.
Source: Adapted from Huang (2020).



The Sydney skyline is engulfed in smoke from various bushfires in NSW © Adobe stock / Nick

The importance of the impact of bushfires on mental health is further evidenced by government funding for mental health support in the aftermath of the 2019-2020 bushfires, amounting to $107m according to the National Bushfire Recovery Fund (PMC, 2020). Given that some mental health impacts may persist long after the event, we can only hope this level of support is sustained.

Based on the available data, we conclude that the health impact of the 2019-2020 bushfires on food workers and their families exceeded $279m, of which $43m (about 15%) was incurred by farm workers and their families. Most of this estimated impact was premature mortality due to smoke exposure. The impact of the bushfires on mental health is an important additional cost but has not been calculated.

THE HEALTH IMPACT OF THE 2019-2020 BUSHFIRES ON FOODWORKERS AND THEIR FAMILIES EXCEEDED $279M.

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9. FOOD PRICE CHANGES AND EMPLOYMENT IMPACTS

There is some evidence that disadvantaged communities experienced disproportionately greater exposure to bushfires during the 2019-2020 season, particularly those residing on the northern and southern coasts of NSW, and in East Gippsland, Victoria (Akter and Grafton, 2021)[37]. As discussed, farmers and other food producers were badly affected by the bushfires in certain areas. Their employees and customers may also have suffered losses or been forced to find alternative employment or food supplies.

In a well-integrated economy like that of Australia, the impacts of bushfires would be expected to filter through the entire food system, from producers to processors, distributors and consumers. Given the extent of the bushfires and the scale of damage to the food system, it is appropriate to consider whether the bushfires may have influenced employment or food prices either regionally or nationally.

Early reports identified the risk of spikes in food prices as the bushfires disrupted food supplies to and from affected areas[38]. IBISWorld (2020) anticipated price increases for some commodities, particularly beef, fruit and vegetables. Any lasting price increases would be a particular concern for the 3.25 m people in Australia (13% of the population) who live below the poverty line (Davidson *et al.*, 2020), as food accounts for a relatively large proportion of their household expenditure[39].

In the end, food supply in Australia was never really in doubt and the observed increases in food prices due to bushfires were modest. Nevertheless, the ABS reported that "*bushfires increased transport costs for some fresh produce*" (ABS, 2021b). This is apparent in the Consumer Price Index (CPI) for the relevant periods, especially for meat and seafood, fruit and vegetables (Table 6).

Considering the economy as a whole, we can refer to a comparative analysis of the impacts of the 2017-2019 drought, the 2019-2020 bushfires and the COVID-19 pandemic by Wittwer (2021). This analysis illustrated both the magnitude of bushfire damage compared to other exogenous shocks, and how the damage was spread across different sectors through market linkages. The author suggested that the impacts of bushfires on food prices were modest compared to other impact channels, notably employment, and were concentrated in certain regions (Box 6).

Based on the available evidence, we conclude that the impacts of bushfires on food prices were modest and short-lived. Impacts on employment were probably more significant, but minimal in comparison to the preceding drought and subsequent pandemic.

EARLY REPORTS IDENTIFIED THE RISK OF SPIKES IN FOOD PRICES AS THE BUSHFIRES DISRUPTED FOOD SUPPLIES TO AND FROM AFFECTED AREAS.

REPORTING PERIOD	MEAT AND SEAFOOD (%)	FRUIT AND VEGETABLES (%	ALL FOOD AND NON-ALCOHOLIC BEVERAGES (%)	OVERALL CONSUMER PRICE INDEX (%)
SEPTEMBER QUARTER 2019 TO DECEMBER QUARTER 2019	2.9 (BEEF AND VEAL ONLY)	6.8 (FRUIT ONLY)	1.3	0.7
DECEMBER QUARTER 2019 TO MARCH QUARTER 2020	2.0	6.0	1.9	0.3

Table 6. Consumer price inflation during the 2019-2020 bushfire season.
Sources:
https://www.abs.gov.au/statistics/economy/price-indexes-and-inflation/consumer-price-index-australia/dec-2019
https://www.abs.gov.au/statistics/economy/price-indexes-and-inflation/consumer-price-index-australia/mar-2020

BOX 6. BUSHFIRES, DROUGHT, AND THE COVID-19 PANDEMIC: A CASE STUDY FROM REGIONAL NSW

Economic modelling of the impacts of drought, bushfires and COVID-19 revealed that regional markets have limited capacity to adapt to large external shocks. Wittwer (2021) used a dynamic Computable General Equilibrium model to examine the impacts of the 2017-2019 drought, 2019-2020 bushfires and the COVID-19 pandemic, in terms of economic output, capital utilisation, employment and wages. The analysis focused on the ABS New England-North West region[40], which was affected by both drought and bushfires, especially along its forested eastern border (Figure 1).

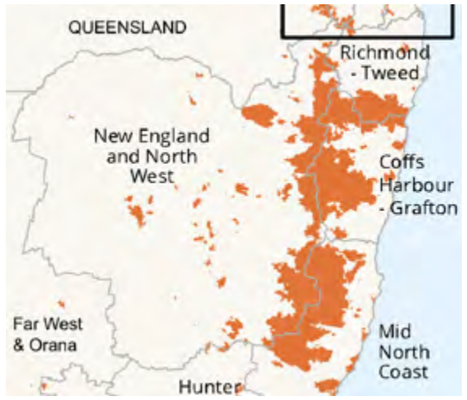

Figure 1. Map of bushfire-affected areas overlaid on Statistical Area Level 4 boundaries (as defined by the Australian Bureau of Statistics).
Source: Adapted from Australian Institute of Health and Welfare (2020).

Relative to a hypothetical baseline scenario of no drought, Wittwer (2021) found that the 2017-2019 drought resulted in a maximum reduction of real gross domestic product (GDP) of over 10% in the New England-North West region (Figure 2). Regional employment declined by a maximum of 5%, equating to a loss of approximately 3,800 jobs. Wittwer (2021) further reported both capital idling and loss of capital, including livestock culling due to drought, but the overall decline in regional income was mainly attributed to lower productivity (i.e. poor growing conditions). At the state level, the impacts of the drought were less dramatic but by no means negligible. Wittwer (2021) estimated that real GDP declined by a maximum of 1.2%, and employment by 0.8% or about 25,000 jobs across NSW.

Livestock cows and bulls in drought and dusty area © Hypervision

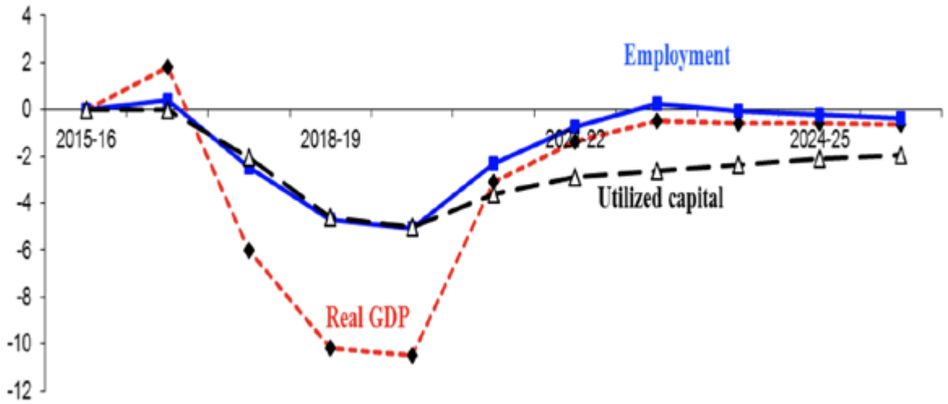

Figure 2. Economic impacts of drought in the New England-North West region.
Source: Wittwer (2021).

Looking next at the national level, Wittwer (2021) summarised the impacts of various shocks using an aggregate measure of 'economic welfare'. This is defined as the discounted present value of private plus government consumption, less net foreign liabilities (i.e., transfers). In the case of the 2017-2019 drought, Witter estimated national economic welfare losses of $43bn relative to the baseline scenario.

Using the same metric to assess the impacts of the 2019-2020 bushfires, Wittwer (2021) further estimated welfare losses of around $8bn at a national level. Modelled results revealed substantial declines in revenue from tourism and agriculture. Note this estimate excluded the value of human lives lost or environmental impacts.

Finally, Wittwer (2021) examined the impact of the COVID-19 pandemic. In this case the driver of economic impact was a collapse in demand and a shift in the supply of labour, as workers were furloughed. Even with optimistic assumptions about the pace of recovery, the study estimated total welfare losses from the pandemic at $100bn nationally. For comparison, the ABS reported a 7% decline in GDP in the quarter ending June 2020, although the Australian economy later rebounded, partly due to government stimulus (ABS, 2021c).

While no model can capture all impacts or policy responses, and GDP is a notoriously poor measure of the impacts of natural disasters (Dixon, 2020), the analysis by Wittwer (2021) offers perspective on the magnitude of the impacts of the 2019-2020 bushfires, relative to other recent economic shocks. In particular, the modelling in Witter suggested that the impacts of the bushfires on national economic welfare were about one-fifth of the impacts of the 2017-2019 drought, and less than 8% of the economic impacts of the COVID-19 pandemic. This may reflect the geographic concentration of the bushfires as well as the economic metric used by Wittwer to assess impacts.

Bushfires and droughts are regular features of Australian rural life and livelihoods. Arguably the economic impacts of drought and bushfires should be considered together, as the fires were exacerbated by drought and both events are symptomatic of the future disruptions expected due to climate change. More damaging shocks, such as the 2020 pandemic, are expected to occur much less frequently.

10. OTHER INDICATORS OF BUSHFIRE IMPACT ON THE FOOD SYSTEM

Another perspective on the losses incurred by the food system in Australia comes from examining funding for bushfire recovery. In the final report of the Royal Commission into National Natural Disaster Arrangements (2020a), total funding for bushfire recovery was reported to be $8.2bn, an amount described as "*likely to be an underestimation*". This included funding from governments, private insurance, charities and businesses. More funding for bushfire recovery has been provided since then, although it has been dwarfed by government responses to the COVID-19 pandemic.

As noted above, the ICA (2020) reported claims for $2.33bn worth of insured losses from the 2019-2020 bushfires as of August 2020. The commonwealth and state and territory governments reported total spending of $2.4bn by June 2021, of which $1.7bn was from the National Bushfire Recovery Fund (NRRA, 2021a). Furthermore, according to the Royal Commission, charities and businesses are estimated to have donated at least $500m in response to the bushfires. Many people provided direct assistance to their neighbours, friends and families that is not reflected in these figures but was probably sizable.

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The share of government bushfire recovery funding for farmers or other food-related businesses is not provided in detail, but an indication can be gleaned from published reports. As of April 2021, the National Bushfire Recovery Fund reported $180m in grants to 2,943 'primary producers', of which the majority were probably food producers. This included grants that were clearly food-related (e.g., $31m allocated to "*bushfire-affected apple growers*").

A clearer picture emerges from an analysis of government grants under the separate Local Economic Recovery Funds, which totalled $310m for 180 projects in the states of NSW, Queensland, South Australia and Victoria as of April 2021 (NRRA, 2021b). The list included 45 projects – 35 of them in NSW, alone – that were clearly related to food and agriculture, and which received over $63m or about 20% of all Local Economic Recovery funding at the time.

Food producers and related businesses in bushfire-affected areas have benefitted both directly and indirectly from a range of different funding channels and support programs. This includes not only funding for 'economic' recovery but also support for debris clean-up, mental health counselling, child support and other actions. The share of food businesses in total public and private funding for bushfire recovery may not be explicit but is likely to be substantial. Nevertheless, the losses that food businesses incurred from the bushfires were probably even greater in most, if not all, cases.

Based on the total share of food-related projects in economic recovery grants reported by four state governments, and if food and agriculture received a similar share of support from all sources, both public and private, we estimate total funding of about $1.6bn (20% of $8.2bn) for bushfire recovery in the food and agriculture sector.

CHARITIES AND BUSINESSES ARE ESTIMATED TO HAVE DONATED AT LEAST $500M IN RESPONSE TO THE BUSHFIRES.

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11. CONCLUSION

Over the past few years, the Australian food system has been affected by severe drought and bushfires, followed immediately by disruption due to the COVID-19 pandemic. More recently, the agriculture sector has benefited from exceptionally favourable growing conditions and high export prices (Agri Investor, 2021). As a result, it can be difficult to discern the specific impacts of the 2019-2020 bushfires on the food system.

Nevertheless, based on the available evidence, we estimate total food system losses from the bushfires amounted to $4-5bn. This is equivalent to 6-8% of the total value of national agricultural output in 2019-2020, which was reported as $61bn (ABS, 2021a). Quantifiable impacts include:

- $2-3bn worth of fire damages to farm property, infrastructure and land;
- Food production losses of around $2bn (including over 100,000 livestock deaths); and
- Health impacts on farmers and other food workers valued at over $279m.

There is some evidence that the bushfires led to short-term increases in food prices nationally, as well as job losses in affected areas, which added to the economic impact.

Insurance pay-outs and government assistance only compensated for some of the above costs. To date, farmers and other food businesses have received around 20% of economic recovery grants from governments. Assuming an equivalent share of all bushfire recovery assistance, which was estimated at $8.2bn by the Royal Commission into National Natural Disaster Arrangements, we estimated total funding for bushfire recovery in food and agriculture at around $1.6bn. Total losses incurred by the food system due to the 2019-2020 bushfires were far greater.

Viewing the impacts of bushfires through an environmental lens, we can interpret at least part of the loss of land values as an erosion of critical natural capital. Similarly, production losses due to fire represent a reduction in the annual 'provisioning services' that ensure both Australians and international customers are supplied with high quality food[41]. Indirect impacts are less well understood but may include a decline in 'regulating' services, such as pollination, clean water supply from forested catchments, and carbon sequestration, which are provided by healthy ecosystems at low or no cost to food producers[42]. Health impacts from exposure to bushfire smoke may be seen as an ecosystem 'disservice'. In short, the 2019-2020 bushfires resulted in major disruption to the natural capital stocks and flows that underpin the Australian food system.

12. RECOMMENDATIONS

This report has tried to quantify the economic impacts of the 2019-2020 bushfires, treating them as an exceptional, one-off event. In reality, the devastating bushfires experienced in 2019-2020 should be seen as part of a pattern of increasingly severe natural catastrophes, together with the preceding drought of 2017-2019 and the subsequent heavy rainfall and widespread flooding that many parts of Australia experienced during 2020-2021.

As climate change intensifies, such large and costly natural disturbances can be expected to occur more frequently. Long-term impacts on the food system may include higher production costs (e.g., for risk mitigation or insurance) or reduced access to finance. Food producers, distributors and policymakers should plan accordingly.

Ongoing human-induced climate change implies that bushfires in Australia are likely to become more frequent and severe, and affect larger areas. The annual fire season is also likely to last longer (Collins *et al.* 2021; Hughes *et al.* 2020; Sharples *et al.*, 2016)[43]. An important question for Australian farmers, food-related businesses and agricultural policymakers is how to protect and sustain food production and distribution in the face of this escalating risk. A related question for food producers is how to manage the land to reduce fire risk and severity, without incurring excessive costs or adverse impacts on productivity.

The immediate priority is to keep people, property and the environment as safe as possible from the impacts of bushfires and other natural disasters, such as floods and drought. Prompted by recent events, the Federal Government has strengthened systems for disaster management and recovery in Australia (Gooley, 2021). Available guidance includes specific advice to state and territory governments, a framework to protect major infrastructure, and general advice to the business community[44].

Given the vulnerability of the food and agriculture sector to bushfires, there is arguably a need for additional sector-specific analysis and support to increase the resilience of agriculture and the Australian food system more generally. The agriculture industry needs to develop better defences against the increasing risk of severe fire, such as:


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- Ensuring that farmers have the knowledge and tools to adapt to climate change and the increasing risk of bushfire, including use of 'nature-based solutions' (Foster *et al.*, 2020);

- Adopting construction and production systems or practices that are less vulnerable and/or more resilient to fire, including the use of 'hardened' infrastructure or fire-resistant plants where appropriate (Murray *et al.*, 2018)[45]; and

- Access to more comprehensive coverage by public and private insurers against tangible and intangible losses, including long-term health impacts and business interruption, while at the same time ensuring that high-risk behaviour is actively discouraged.

Even with concerted efforts, the increasing risk of fire due to climate change is likely to have serious implications for the food system in Australia (Dowdy *et al.*, 2019; Hughes *et al.*, 2015). This underscores the urgency of actions to reduce GHG emissions. No single country or industry can stop climate change alone, but food producers and distributors in Australia have an important role to play, alongside others, in accelerating the transition to a net zero carbon world. This can include:

- Improved soil and vegetation management to increase soil moisture and carbon stores, including preventing land clearing, where this is consistent with managing fuel loads. Due to potential trade-offs with commodity production, this may require stronger incentives for landholders to retain or regenerate suitable vegetation, and a better understanding of how to combine food production with carbon sequestration and other ecosystem services;

- Switching to renewable energy for food production, processing and distribution. For some operators, there may be significant potential earnings from surplus energy generation; and

- Supporting the development of markets for low-carbon-intensity products (e.g., extensive, grass-fed beef and/or plant-based substitutes for animal protein), or for products that are verifiably linked to management practices that support climate resilience and adaptation.

Public subsidies may be justified for these and other potential interventions due to missing markets and positive spill-over effects, as well as to resolve scientific uncertainty.

One opportunity that deserves further investigation is to work with Indigenous communities to integrate cultural burning and carbon farming in fire-prone landscapes across southern and eastern Australia. Recent experience in northern Australia shows that cultural burning can reduce the risk of severe bushfire and net GHG emissions, while also providing income for Indigenous landowners (Russell-Smith, 2015). Such initiatives build on both contemporary science and the historical experience of Indigenous peoples who have used fire as a tool for land management for thousands of years (Bowman *et al.*, 2020; Lee, 2021).

Although Indigenous voices have not always been fully expressed in the development of these initiatives, it may be feasible to apply similar approaches with greater Indigenous influence in other bushfire-prone regions (Farra, 2021; Foley, 2016; Royal Commission into National Natural Disaster Arrangements, 2020b; Steffensen, 2020). In any case, Australian governments should make greater efforts to involve Indigenous people in the design and implementation of land use policies and programs, including prescribed burning where appropriate, and the integration of practices that reduce bushfire risk in food production systems.

ANNEX 1. ACCOUNTING FOR BUSHFIRE GREENHOUSE GAS EMISSIONS

Greenhouse gas emissions (GHG) from the 2019-2020 bushfires do not appear in the Federal Government estimates of national GHG emissions in 2020, which are reported as 513 Mt CO_2-e (DISER, 2020b). Aside from some small emissions due to prescribed burning, GHG emissions from bushfires are likewise missing from the projected decline in future emissions that will be required to meet the government's modest target of a 26-28% reduction below 2005 levels by the year 2030.

One reason for this omission is that the GHG accounting and reporting rules developed by the Intergovernmental Panel on Climate Change (IPCC) of the United Nations, which Australia follows, exclude GHG emissions from natural (unintentional) bushfires. According to the IPCC approach, emissions from bushfires are considered a 'natural disturbance' over which governments have limited control; hence they are not counted against national emissions targets[46].

Historically, it was assumed that bushfire emissions are completely absorbed by natural vegetation regrowth. However, natural regeneration may not restore lost carbon for many years (Johns, 2020). Moreover, climate change is leading to higher average temperatures as well as widespread changes in precipitation. Across Australia, as in other parts of the world, the risk of bushfires is increasing (Hessburg *et al.*, 2021; Mackey *et al.*, 2021). Some Australian forests may not fully recover from the 2019-2020 bushfires due to changing climatic conditions (Gould *et al.*, 2021).

We might expect that more frequent and more extensive fires, due to climate change, would have adverse impacts on the capacity of soils and vegetation to store carbon. The evidence is mixed, however, due to the difficulty of isolating the effects of bushfires from other influences on forest carbon storage (Gordon *et al.*, 2018; Collins *et al.*, 2019; Bennett *et al.*, 2020; Bowman *et al.*, 2020; van der Velde *et al.*, 2021).

More generally, the effect of climate change on the carbon storage capacity of natural ecosystems is variable (Cook-Patton *et al.*, 2020). Emissions due to bushfires may be offset, at least in part, by the fertilizer effect of higher CO_2 concentrations in the atmosphere, which stimulates plant growth, or by the pyrogenic carbon created when wood is combusted (Jones *et al.*, 2019). Particulates in bushfire smoke may moderate climate impacts by reflecting solar radiation (Fasullo *et al.*, 2021).

Australian bush recovers after the bushfires of 2019/20 © Adobe stock / Natalie

The long-term impacts of climate change on Australian forests, bushfire risk, carbon emissions and carbon storage are important topics for future research. How do changes in the fire disturbance regime, due to climate change or land management, affect the structure and composition of Australian forests? How will this affect regrowth and carbon sequestration after fires? Can bushfires continue to be considered a natural phenomenon or rather as something that human behaviour can and does influence? If the latter is true, then should governments report on and seek to reduce bushfire emissions in the same way as other sources of GHG emissions?

Even in the absence of definitive answers to these questions, it is evident that Australian forests do not always recover quickly or fully from bushfires. So long as residual emissions remain in the atmosphere, they will contribute to climate change. Moreover, it is increasingly clear that climate change is primarily driven by human activity and that, due to the changing climate, bushfires are becoming more frequent and widespread. At least some of the damage from bushfires is therefore a result of climate change and part of our collective responsibility. This also implies that effective action to reduce bushfire risk should be counted as a contribution to meeting national GHG emissions reduction targets.

SOME ECOSYSTEMS MAY NOT FULLY RECOVER FROM THE 2019-2020 BUSHFIRES TO CHANGED CONDITIONS AFTER FIRE.

ANNEX 2. VALUING GREENHOUSE GAS EMISSIONS FROM BUSHFIRES

As part of our assessment of the economic impacts of the 2019-2020 bushfires, we considered the costs of greenhouse gas (GHG) emissions and the benefits of mitigation. To this end, we reviewed available data on GHG emissions, made conservative assumptions about the rate of forest regrowth, and applied a range of alternative prices to value aggregate emissions.

Total GHG emissions from the 2019-2020 bushfire season were reported as 830-940 Mt CO_2-e by the Department of Industry, Science, Energy and Resources (DISER, 2020a). The higher figure represents gross or 'absolute' emissions of around 940 Mt CO_2-e up to 11 February 2020, while the lower figure is a net estimate, after deducting "*sequestration equivalent to negative 110 Mt CO_2-e resulting from recovery after this season's and previous seasons' fires*" (DISER, 2020a).

The DISER is optimistic about forest recovery after the 2019-2020 bushfires, stating that "*the recovery of the forest is expected to be complete*" (DISER, 2020a). Its report also provides a case study of forest carbon sequestration following bushfires in the ACT in 2003, showing cumulative recovery of 84% of carbon emissions after 10 years and 96% after 16 years. For our analysis, we assumed that 90-95% of GHG emissions from the 2019-2020 bushfires would be absorbed by vegetation regrowth during the 10 years following the bushfires. Based on the emissions figures noted above, this implies residual emissions of 41.5-94 Mt CO_2-e by 2030.

To value these residual emissions in economic terms, we applied the Social Cost of Carbon (SCC), which represents an estimate of the global damage resulting from the emission of one additional tonne of CO_2e (Rennert and Kingdon, 2019). The National Academies of Sciences, Engineering, and Medicine in the United States forecast that the SCC in 2020 would reach US$42 per tonne of CO_2-e, expressed in 2007 dollars (National Academies, 2017).

Note that this SCC estimate may understate the damages of climate change and the benefits of mitigation, as it does not reflect some relevant differences across countries (Ricke *et al.*, 2018). It also ignores certain non-market benefits of natural capital and ecosystem services (Bastien-Olvera and Moore, 2020). Nevertheless, economists generally support using the SCC to value climate change impacts and policy options (Aldy *et al.*, 2021).

We adjusted the SCC value reported by the National Academies (2017) to account for inflation[47] and converted the updated value into Australian dollars at the market exchange rate, yielding a value of $77.34 per tonne CO_2-e[48]. This unit cost was then multiplied by the volume of residual emissions assumed to remain in the atmosphere after 10 years to derive damage estimates, which ranged from $3.21bn (assuming 830 Mt CO_2-e net GHG emissions, of which 5% remains after 10 years) up to $7.27bn (assuming 940 Mt CO_2-e gross emissions, of which 10% remains after 10 years).

More elaborate analysis might account for short-term damages caused by the relatively large share of GHG emissions that contribute to global heating before it is offset through forest regrowth. Further analysis might also account for the expected rise in both the SCC (Rennert *et al.*, 2021) and carbon offset prices (Reputex, 2021; Turner *et al.*, 2021). These refinements would tend to increase both the total volume of GHG emissions to be valued and the unit cost per tonne. Our simple calculation is therefore probably a conservative estimate of economic impact.

Finally, we calculated the cost of mitigating residual GHG emissions from the 2019-2020 bushfires, using data on the price of carbon offsets ('credits'). A conservative estimate was derived using the auction settlement price of Australian Carbon Credit Units (ACCUs) in Australia's regulated market as of September 2020, which was reported as $15.74 per tonne CO_2-e[49]. This yielded mitigation costs ranging from $653m to $1.48bn, depending on the rate of forest recovery as above.

Actual mitigation costs could be higher or lower depending on the source of credits and prices at the time of purchase. For comparison, the contemporary price of an emission allowance (equivalent to 1 tonne CO_2-e) in the European Union Emissions Trading Scheme was equivalent to around $51[50], while the auction settlement price for GHG emission allowances in the US State of California's carbon Cap-and-Trade Program was equivalent to $22 per tonne CO_2-e[51].

At these prices, the cost of mitigating the residual 2019-2020 bushfire emissions would be higher, ranging from $920m (using the Californian carbon price and assuming that 5% of net emissions remain after 10 years) up to $4.84bn (using the EU allowance price and assuming that 10% of gross emissions remain after 10 years). In all scenarios, the cost of mitigation is less than the value of damages avoided due to climate change.

ANNEX 3. MAPPING AGRICULTURAL LAND VALUES IN AUSTRALIA AND OVERLAYS WITH FIRE AND LAND USE

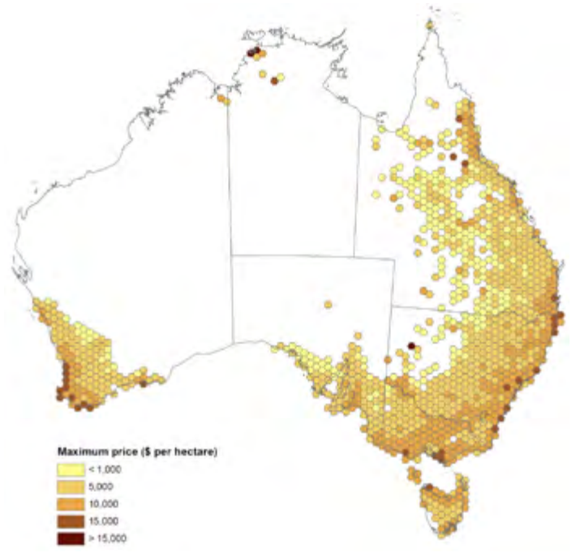
The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) published a report by Chancellor *et al.* (2019) that analysed the determinants of farmland values in Australia. The analysis was based on a dataset of 700,424 transactions on 349,217 unique properties over the period from 1900 to 2019. For their analysis, Chancellor *et al.* removed from the dataset all "*hobby farms, mine sites, urban residences, and non-broadacre farms such as irrigated horticulture*". The final dataset included 166,994 broadacre farmland transactions over the period of 1975-2018.

The cleaned spatial data on farmland transactions was overlaid with other farm-specific attributes, including transport costs to nearby markets, climate, vegetation, topography, buildings, land use and soil condition. The authors also overlaid non-farm-specific variables, including state-level agricultural productivity, rural debt, the year of sale and other variables. Finally, Chancellor *et al.* (2019) analysed data on farmland transactions using 'hedonic' modelling to isolate the specific influence of property attributes on market price. Prices were adjusted for inflation to 2018 values.

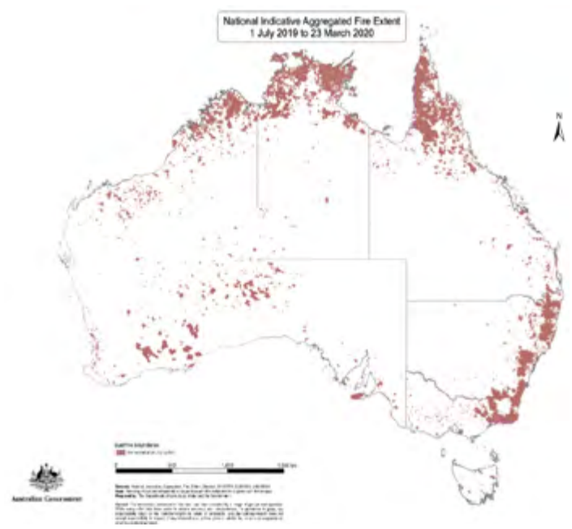
Based on their analysis, Chancellor *et al.* (2019) generated a map of farmland prices in areas considered suitable for broadacre farming. The data is displayed as ranges of maximum prices within hexagons ('hexbins'), each of which is 50km per side, giving a surface area of around 650,000ha per hexbin.

Huang (2020) combined Map 1 (originally labelled as 'Map A5' in Chancellor *et al.*, 2019) with separately sourced maps of the extent of the 2019-2020 bushfires (Map 2) and land use in 2018 (Map 3) to create an overlay (Map 4). All four maps are reproduced here for reference.

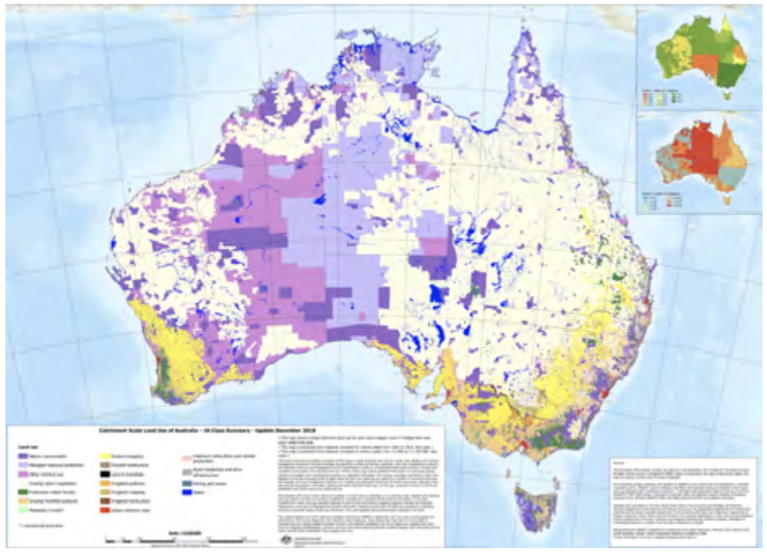
Based on visual inspection of these maps, Huang counted the number of hexbins in areas affected by bushfires in each state, where the primary land use was agriculture. He then calculated the weighted average value of burnt farmland in each state, using the top of the range of farmland values as reported by Chancellor *et al.* (2019). For this report, we used the mid-point estimates of farmland value.



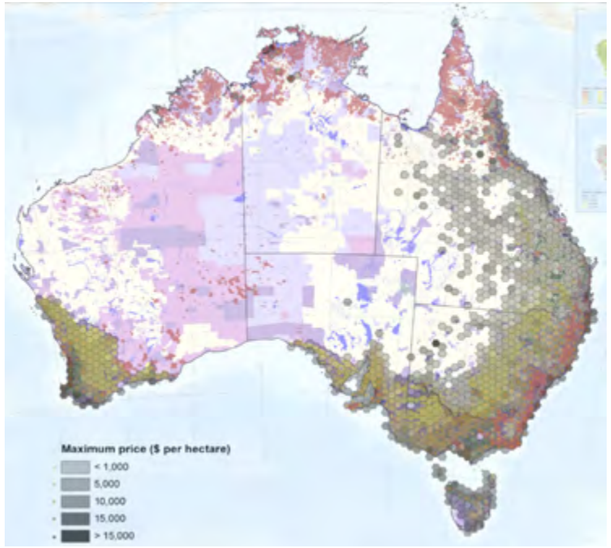
Map 1. Price per hectare (maximum) by parcel in clean dataset 1975-2018 (as hexbins)
Source: Chancellor *et al.* (2019).



Map 2. National Indicative Aggregated Fire Extent (1 July 2019-23 March 2020).
Source: National Indicative Aggregated Fire Extent Dataset, cited in Huang (2020).



Map 3. Catchment Scale Land Use of Australia – 18 Class Summary – Updated December 2018.
Source: ABARES (2019a).



Map 4. Overlay of fire extent, land use and land value
Source: Huang (2020).

ENDNOTES

1. Climate change impacts on bushfire risk are well-documented, including in Australia (Harris and Lucas, 2019; Jones *et al.*, 2020; Abram *et al.*, 2021; Collins *et al.* 2021; van Oldenborgh *et al.*, 2021). There is mixed evidence that land management can enhance or compound climate-driven changes in wildfire risk (Attiwill *et al.*, 2014; Lindenmayer *et al.*, 2020; Smith *et al.*, 2020; Adams *et al.*, 2021; Bowman *et al.*, 2021; Zylstra *et al.*, 2021).

2. Ecosystem services are typically described as positive contributions to human wellbeing, but ecosystems and associated ecological processes can also have negative impacts on human welfare (Sil *et al.*, 2019).

3. The impacts of bushfires on regulating ecosystem services are not well-documented but the topic has gained traction with researchers (Banza *et al.*, 2019; Vukomanovic and Steelman, 2019; Elimbi Moudio *et al.*, 2021; Lecina-Diaz *et al.*, 2021; Pereira *et al.*, 2021; and Raviv *et al.*, 2021.)

4. The NSW Rural Fire Service referred to private landholders working alongside the NSW RFS as 'farm fire units', noting that "*farmers are a critical part of the fire-fighting effort, and an important partner in managing and responding to the threat of fire*" in its official submission to the NSW Bushfire Inquiry (NSW Rural Fire Service, 2020).

5. See for example: https://permaculturesydneyinstitute.org/2020/02/permaculture-strategies-for-fire-prevention-preparedness/; https://issuu.com/cfastrategiccommunications/docs/3898_cfa_ontheland_web; http://www.farmforestline.com.au/pages/5.5.5.2_strategies.html; https://www.farmstyle.com.au/news/bushfire-preparation-and-management-small-farms; https://science.sciencemag.org/content/359/6379/1001.1

6. Bushfires typically affect large areas of northern Australia, but the economic impacts tend to be relatively modest, due to low population density and greater reliance on extensive agricultural production systems (Russell-Smith *et al.*, 2003; 2007).

7. https://www.agriculture.gov.au/abares

8. https://theconversation.com/us

9. https://www.ibisworld.com/

10. https://www.agriinvestor.com/

11. A final report on Phase 2 of the inquiry was submitted to the Victorian Government on 30 July 2021 but had not been released publicly at the time of writing this report.

12. See for example: Department of the Prime Minister and Cabinet (2020).

13. The ICA notes in a separate submission to the NSW bushfire inquiry that claims filed may understate actual damages, due to non-insurance and under-insurance by property owners (Insurance Council of Australia, 2020c).

14. The effects of bushfire on soils can also result in off-site impacts. Areas that have been burnt typically deliver more sediment into nearby rivers and streams when it rains heavily (Tulau and McInnes-Clarke, 2015).

15. Another analysis revealed a decline in land sales in areas heavily affected by the 2019-2020 bushfires (Rural Bank, 2021), implying that land value losses tended towards the higher end of the range estimated by the Valuer General NSW.

16. The map of fire extent used by Huang (2020) was obtained from the National Indicative Aggregated Fire Extent Dataset (https://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B9ACDCB09-0364-4FE8-9459-2A56C792C743%7D). The original map is no longer available online, hence the reference provided here is to a more recent map shown on the website of the Royal Commission into National Natural Disaster Arrangements (DAWE, 2020).

17. Agri Investor reported that 2.46 m ha of agricultural land was affected by the 2019-2020 bushfires. This estimate is based on work by Digital Agriculture Services (https://digitalagricultureservices.com/), which overlaid fire boundary maps from the Emergency Management Spatial Information Network Australia (https://www.emsina.org/) onto land use maps obtained from ABARES (2019a).

18. The average price of farmland shown in Chancellor *et al.* (2019) was slightly more than $6,000/ha in 2018 (Fig. 2, p. 12). This estimate is for 'dryland broadacre farmland' and excludes irrigated farms, dairy farms, sugarcane, horticulture, very small farms, 'lifestyle' or 'hobby farms', as well as extreme prices (high or low). See Annex 3 for details.

19. Huang (2020) added his own estimates of burnt agricultural land in the ACT (3,000 ha) and Western Australia (170,000 ha), which were not included in the Agri Investor (2020) report.

20. Chancellor *et al.* (2019) provide a map (A5) showing the estimated 'maximum' price per ha for equal-sized hexagons ('hexbins') in five price bands: $84-1,000; $1,001-5,000; $5,001-10,000; $10,001-15,000; and $15,001-20,361/ha.

21. We considered only four price bands ($500, $3,000, $7,500, and $12,500/ha), as no hexbins in the highest price range shown in Chancellor *et al.* (2019) (Map A5) overlap with the burnt areas considered by Huang (2020).

22. The net capital stock included: non-dwelling construction (46% of net value), machinery and equipment (37%), cultivated biological resources (17%), research and development (1%) and computer software (0.1%).

23. Livestock is considered alongside current crop production, on the basis that most Australian farms do not keep livestock for more than one or two seasons (https://www.farmtransparency.org/kb/abattoirs/48-age-animals-slaughtered).

24. See for example: https://www.theland.com.au/story/6596244/fire-sparks-massive-upper-murray-fish-kill/; https://www.abc.net.au/news/2020-01-25/bushfire-ash-in-waterways-could-affect-murray-quality/11896592; https://www.abc.net.au/news/2020-02-02/generations-of-farming-go-up-in-smoke-in-bushfire-crisis/11897718?nw=0; https://www.smh.com.au/environment/conservation/bushfire-devastation-for-beekeepers-as-honey-production-plummets-20200313-p549sn.html [accessed 16 April 2021].

25. As noted above, Agri Investor (2020) reported a total of 2.46 m ha of agricultural land burnt in 2019-2020, based on analysis by Digital Agriculture Services, but this excludes burnt farmland in the ACT (3,000 ha) and WA (170,000 ha).

26. Huang (2020) compiled evidence that smoke from bushfires influences crop yields. Yue *et al.* (2018) suggested that the influence of ozone exceeds that of particulate aerosols (PM_{10} and $PM_{2.5}$), implying a net reduction in crop productivity due to smoke. In contrast, Hemes *et al.* (2020) argued that ozone does not have a significant negative impact compared to the positive impact of particulate aerosols on plant productivity, concluding that smoke may promote a net increase in crop productivity. Bell *et al.* (2013) report that short exposure time to smoke had limited physiological effects on grapevine leaves. The net impact of smoke on crop productivity is unknown but probably in the range of ±1%.

27. IBISWorld (2020) estimated lost revenue from livestock at over $1bn, which is equivalent to an average of $10,000 per animal. This seems exaggerated. Assuming 100,000 livestock were killed in the bushfires, of which 70,000 were sheep, and using ABARES commodity price data for 2019-2020, Huang (2020) calculated the value of livestock losses at $64m.

28. The 2019-2020 farm-gate price of milk was reported as 52.4 cents/L (ABARES, 2020).

29. This interpretation is bolstered by crop reports for 2020-2021, which show an increase in production between the initial forecasts (ABARES, 2020a) and more recent estimates (ABARES, 2021b), especially in NSW, due to more favourable growing conditions during La Niña (BOM, 2016; https://nff.org.au/media-release/best-year-yet-for-agriculture-100-billion-in-view/).

30. https://www2.deloitte.com/au/en/pages/economics/articles/building-australias-natural-disaster-resilience.html [Accessed 8 April 2021].

31. The difference between insured losses and other tangible costs reflects estimated uninsured losses and government disaster assistance, as well as agricultural output losses, costs of evacuation and homelessness, other damage to homes and commercial properties, and emergency response costs. See Table 3.2 in Deloitte (2016).

32. See Deloitte (2017), Table B.2 in 'Appendix B: Methodology for estimating total economic costs'.

33. Johnston *et al.* (2021) used the recommended value of a statistical life from a Federal Government guidance note published in 2014, which in turn relied on an estimate originally prepared by Abelson (2007). An updated estimate of the value of a statistical life in Australia, reflecting recent wage price inflation, recommends a value of $5m (Office of Best Practice Regulation, 2020).

34. The estimated share of farm workers in Australia's total population in Huang (2020) was based on data from ABARES describing the agricultural workforce in 2016 (https://www.agriculture.gov.au/abares/publications/insights/snapshot-of-australias-agricultural-workforce) and data from the ABS on the Australian population as of 31 March 2020 (https://www.abs.gov.au/statistics/people/population/national-state-and-territory-population/mar-2020).

35. This is equivalent to an average health cost of $149 per worker, which includes health impacts on unemployed people. Recall that the estimate developed by Johnston *et al.* (2021) is for approximately 80% of Australia's population. The remaining 20% was not significantly exposed to smoke from the 2019-2020 bushfires in forested areas in Australia. For this analysis we assume that the same 80:20 breakdown applies equally to agricultural and other workers (and their families).

36. This includes agriculture, forestry and fishing support services (24,548 persons employed in February 2020); food product manufacturing (232,769); beverage and tobacco product manufacturing (33,735); grocery, liquor and tobacco product wholesaling (59,050); food retailing (395,570); and food and beverage services (836,970). See ABS (2020).

37. Visual inspection of maps of economic disadvantage in NSW and Victoria reveal a striking overlap with areas most severely affected by the bushfires in 2019-2020 (https://maps.ncoss.org.au; http://povertymaps.vcoss.org.au).

38. See for example: https://thenewdaily.com.au/finance/consumer/2020/01/14/fresh-food-price-rises-bushfires/; https://www.abc.net.au/news/2020-01-14/vegetable-prices-in-australia-set-to-rise-fire-drought-impact/11866038; https://www.smh.com.au/politics/federal/food-prices-surge-as-drought-impact-starts-to-bite-20200129-p53vno.html; https://www.afr.com/companies/agriculture/bushfires-hit-fruit-vegetable-supply-lines-20200115-p53rps; https://www.4bc.com.au/food-prices-to-spike-after-devastating-bushfire-effects/

39. "*Food and non-alcoholic beverages accounted for 19% and 18% of household spending on goods and services of low and middle income households, compared to 14% for high income households*" (https://www.abs.gov.au/statistics/economy/finance/household-expenditure-survey-australia-summary-results/latest-release#income-and-spending) [Accessed 16 April 2021].

40. https://www.agriculture.gov.au/abares/research-topics/aboutmyregion/nsw-new-england

41. Provisioning services refer to products obtained from ecosystems and are one of four categories of ecosystem services defined in the UN Millennium Ecosystem Assessment, alongside regulating, cultural and supporting services (MA, 2003). See also the European Environment Agency's Common International Classification of Ecosystem Services (CICES), which provides a simpler classification of ecosystem services and clarifies linkages with systems of environmental economic accounting (Haines-Young and Potschin, 2018).

42. Bushfire impacts on wild crop pollinators are uncertain but may be considerable (Brown *et al.*, 2017; Banza *et al.*, 2019; Saunders *et al.*, 2021). Farmers can play a key role in conserving or restoring habitat for pollinators (Lentini *et al.*, 2012). See also: https://www.farmonline.com.au/story/6656442/croppers-to-feel-the-yield-sting-from-devastating-bee-losses/; https://www.goodfruitandvegetables.com.au/story/6613481/bushfires-prompt-heightened-pollinator-research/

43. Attribution of drought conditions to climate change is not definitive (Chiew *et al.*, 2011; Cook *et al.*, 2018; Grose *et al.*, 2017; King *et al.*, 2020; van Dijk *et al.*, 2013). However, the balance of evidence points to a growing risk of drought in many regions (Australian Government, 2019), which is likely to exacerbate bushfire risk (Abram *et al.*, 2021).

44. See Deloitte Access Economics for the Australian Business Roundtable for Disaster Resilience and Safer Communities (https://www2.deloitte.com/au/en/pages/economics/articles/building-australias-natural-disaster-resilience.html). The roundtable recently established an initiative to develop "methodologies for understanding the value of a resilience-building asset, network, feature or activity" (http://resiliencevaluation.com.au). State and federal governments provide additional resources on disaster management and resilience.

45. See also: http://anpsa.org.au/fire.html

46. The IPCC approach to calculating the 'background' level of natural disturbance, including bushfire emissions, and the application of this method in Australia are set out in Roxburgh *et al.* (2014).

47. 1.27 between January 2007 and December 2019, according to: https://data.bls.gov/cgi-bin/cpicalc.pl

48. 1.45 AUD/USD on 15 January 2020, according to: https://www.x-rates.com

49. http://www.cleanenergyregulator.gov.au/ERF/Pages/Auctions%20results/September%202020/Auction-September-2020.aspx

50. https://carbon-pulse.com/category/eu-ets/

51. https://ww2.arb.ca.gov/sites/default/files/2020-08/results_summary.pdf

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