CLIMATE COUNCIL

HITTING HOME: THE COMPOUNDING COSTS OF CLIMATE INACTION

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Published by the Climate Council of Australia Limited.

ISBN: 978-1-922404-13-8 (print)
978-1-922404-12-1 (digital)

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Cover image: Townsville Floods. Andrew Rankin / Australian Associated Press.

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Key findings

1

2019-20 was an exceptionally intense period for climate-fuelled extreme weather, with heavy costs felt in Australia and around the world.

› An extraordinary run of events, including unprecedented fire seasons in Australia and the US, a record-breaking North Atlantic hurricane season, and an astonishing series of heat records, paint a sobering portrait of our escalating climate crisis.

› Extreme heat events are rapidly on the rise both here, and overseas. The latest science projects that by 2100, annual deaths from extreme heat worldwide will outstrip all COVID-19 deaths recorded in 2020.

› The cost of extreme weather disasters in Australia has more than doubled since the 1970s, reaching $35 billion for the decade 2010-2019.

› Australians are five times more likely to be displaced by a climate-fuelled disaster than someone living in Europe. In the Pacific, that risk is 100 times higher.

› Australia is surrounded by many countries that are acutely vulnerable to climate impacts. Those unfolding regional impacts may soon become as damaging to Australia as those that strike us directly.

2

Some extreme weather events show 'tipping point' behaviour when a critical level of heat or drought triggers a massive, devastating event.

› In 2019-20, we ushered in a new and dangerous era of megafires that ravaged Australia, Brazil, Siberia and the US West Coast. During the massive Black Summer bushfires, we likely crossed a tipping point for Australia's temperate broadleaf and mixed forests. In any typical fire season, 2-3 percent of these forests burn, but in the Black Summer 21 percent burned.

› Around half of all hard corals along the Great Barrier Reef perished during successive mass bleaching events in the past five years. We are on track to eliminate all of Australia's and the world's tropical coral reefs.

3

Ignoring climate change is deadly. Australians are now paying the price for our own and the world's failure to reduce emissions quickly enough or deeply enough.

- Governments, like the Australian Government, which have failed to substantially reduce emissions over the past decade have sentenced Australians, and communities worldwide, to a far more dangerous future than if they had responded to repeated warnings from scientists.
- Due to this past inaction, gradual, measured steps are not enough to avoid catastrophe. At this point, only truly transformative action is required. That means at least halving global emissions over the coming decade, and reaching net zero emissions globally by 2040 at the latest.

4

No developed country has more to lose from climate change-fuelled extreme weather, or more to gain as the world transforms to a zero-carbon economy, than Australia does.

- We need bold, concerted action across all levels of government, business, industry and community to reduce Australia's emissions to net zero as soon as possible, and prepare for worsening extreme weather events.
- Almost all of Australia's major trading partners and strategic allies, as well as Australian state and territories, are now committed to net zero emissions by around mid-century. This includes countries that buy more than 70% of our coal and gas exports.
- Australia can position itself as a global powerhouse of renewable energy and clean industries, ensuring our prosperity and security in a post-carbon world.

1. Introduction

Many will remember 2020 as the year of the COVID-19 pandemic. Yet for millions of people around the world the virus served as a backdrop to another battle as we lived through the most intense period yet of climate-fuelled extreme weather.

Unprecedented fires, extreme heat, powerful cyclones and devastating floods all occurred in 2019-20, capping off a decade in which the climate crisis hit hard.

This report outlines the latest science on how climate change is driving more destructive heatwaves, downpours, cyclones, droughts, fires and other extreme weather events. It highlights significant events in Australia and around the world from the past two years. Taken alone, any one of the events described in this report – from Australia's Black Summer bushfires to the record-breaking North Atlantic hurricane season, or the remarkable Siberian heatwave – would mark the year as unusual. Taken together, they paint a disturbing portrait of our rapidly escalating climate emergency.

There is no doubt that we have entered an era of consequences arising from decades of climate inaction and delay. We are all paying dearly for the failure of governments to respond adequately to repeated warnings from scientists and those on the frontlines of this unfolding crisis. It is now clear that we must learn to live in a new age of megafires and other climate impacts that are locked in over the coming years. It is equally clear that far greater dangers lie ahead if we fail to act with the urgency and determination that the science demands.

As this report shows, communities here and abroad are already reeling from unprecedented disasters occurring under a temperature rise of around 1.1°C above pre-industrial levels. Every fraction of a degree more will result in even more extreme events.

For Australia, the devastating Black Summer fires, a crippling drought, and yet another mass bleaching of the Great Barrier Reef affirmed our acute vulnerability to climate impacts. Similarly, as the world's third largest exporter of fossil fuels, behind only Russia and Saudi Arabia (Office of the Chief Economist 2020), we are highly exposed to economic losses and job cuts as the world shifts towards a new, clean economy. Yet we could still pivot, and prosper in the emerging renewables-driven economy with natural advantages that are the envy of countries around the globe.

It is no exaggeration to say that decisions made over the coming year, as governments aim to reboot their economies from the COVID-19 crisis and we head toward the next critical round of international climate negotiations, may represent our last chance to secure a future in which our children can survive and thrive.

The global community could have taken credible climate action much earlier. Beginning a decade or two ago, we could have taken more gradual, measured steps that avoided the worsening impacts to come. That time has passed. At this point, only truly, transformative action will avoid us slipping from a crisis towards a full-blown catastrophe. That means at least halving global emissions over the coming decade, and reaching net zero emissions globally by 2040 at the latest (Steffen et al. 2020).

Given the immediate, rapidly escalating risks of climate change that we now face, every 0.1°C of warming matters, and every gigaton of carbon left in the ground will be measured in lives and livelihoods saved. Even taking into account the series of strengthened commitments made by the world's biggest emitters in 2020, optimistic assessments say we are still on track for heating of well over 2°C (Climate Action Tracker 2020), and a barely survivable future.

The events of 2019-20 have provided us with the clearest picture yet of why far stronger and more urgent action is required.

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2. Extreme weather fuelled by climate change

When we change the climate, we change the conditions under which all shorter-term weather events form. Global emissions of greenhouse gases are making our climate system hotter and more energetic. This is leading to a marked increase in the frequency and/or severity of destructive weather events: extreme heat, intense downpours, powerful cyclones, crippling droughts, and dangerous fire weather. While no country is immune to the climate crisis, its impacts are not shared evenly. Already a land of extremes, Australia is perhaps the most vulnerable among all developed countries.

Over the past few years, attribution science has made significant progress. It tells us, with increasing confidence, the likelihood that a given event could have occurred without climate change, or the extent to which an event may have worsened due to climate change. For example, Australia's record hot spring in 2020 was deemed "virtually impossible" without the influence of human-induced climate change (Karoly 2020).

The following sections examine the influence of a warming climate on different types of extreme weather events, and include case studies of some of the unprecedented events that took place in 2019-20.

Australia's record hot spring in 2020 was deemed "virtually impossible" without climate change.

2.1 Extreme heat

The seven hottest years on record globally all occurred in the past seven years. In other words, each year between 2014-2020 was warmer than any year recorded in history prior to 2014. In decadal terms, the 2010s were warmer than any preceding decade; a full 0.2°C warmer than 2000-2009, representing a sharp acceleration in the rate of temperature increase.[1]

Today the world has warmed by around 1.1°C since pre-industrial times. However, this warming is not spread evenly, and many land areas are already significantly hotter than the global average. For example, Australia has warmed on average by 1.44°C since national records began in 1910 (CSIRO and BoM 2020).[2]

In a single year (2019), Australia recorded 33 days above 39 degrees – that's more than all such days recorded over the previous 60 years (1960-2018).

1 The global temperature has increased at an average rate of 0.07°C per decade since the 1880s. Most warming has occurred since the 1950s.

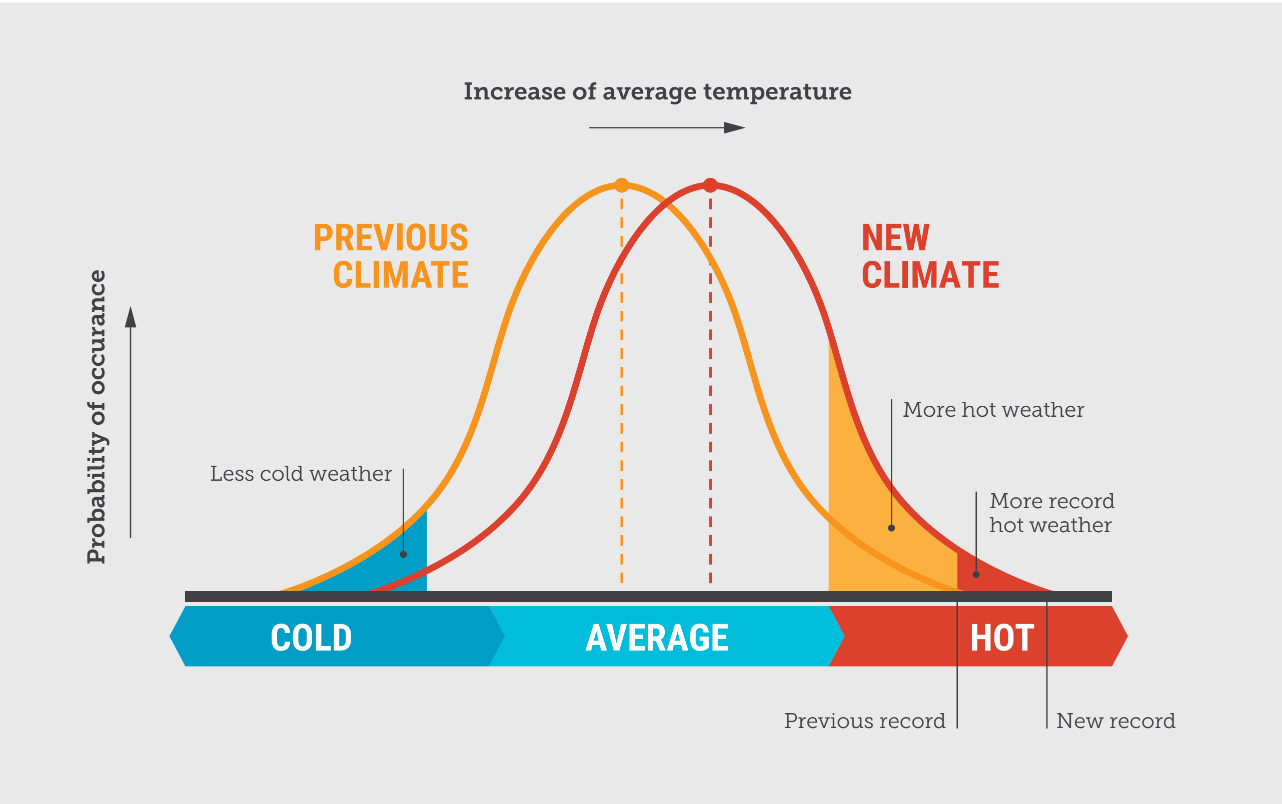
2 If using a pre-industrial baseline rather than 1910, then by 2019 Australia had warmed by more than 1.5°C.

As illustrated by Figure 1, an increase in global average temperatures means a marked increase in the probability of extreme and record-breaking hot weather, and a decrease in the probability of extreme cold weather. Climate change is creating more record hot days, and making heatwaves longer, more intense and more frequent (Steffen et al. 2019). In 2019, Australia experienced 43 "extremely warm days", more than triple the number recorded in any year last century (CSIRO and BoM 2020). Even more strikingly, in terms of the average *maximum* temperature recorded across Australia, there were 33 days that exceeded 39°C – more than the total number observed in the entire 1960-2018 period (CSIRO and BoM 2020).

Heatwaves are by far the most lethal extreme weather risk facing Australians. Since 1890, heatwaves have killed more Australians than bushfires, cyclones, earthquakes, floods, and severe storms combined (DIT 2013). Extreme heat can also be deadly for Australian animals. In late 2018, more than a third of the county's population of spectacled flying foxes died in a single heatwave (Welbergen 2019). In January 2019, extreme heat led to the death of more than 90 wild horses near Alice Springs (BBC 2019).

In 2020, the US-based National Bureau of Economic Research published new projections for the number of people likely to die from climate change-fuelled extreme

Figure 1: When average temperatures increase and the curve showing the distribution of temperatures moves to the right, there is a significantly greater probability of experiencing very hot, and record hot, weather.



heat. It concluded that if no action is taken, on average there would be 221 additional deaths per 100,000 people globally each year by 2100 – roughly equivalent to all deaths from cardiovascular disease today. Even after factoring in efforts to adapt to a changing climate, the study still projects an extra 73 deaths per 100,000 people annually by 2100 – which is greater than the number of all people who died from COVID-19 in 2020. While climate change affects all countries and communities, the study reaffirmed the stark inequity of the climate crisis, with poor communities – the same people who have contributed the least to global greenhouse gas emissions – likely to suffer far more deaths (Carleton et al. 2020).

Scientists expect that by 2100, climate change-fuelled extreme heat will kill more people across the globe annually than COVID-19 did in 2020.

Figure 2: Poor communities in developing countries are likely to suffer far more deaths from climate change, despite having contributed the least to the problem.

The oceans also provide evidence for climate-fuelled temperature extremes. The vast majority of the excess heat trapped by greenhouse gas emissions – more than 90 percent – is absorbed by oceans. Today this is an amount of energy equivalent to around five Hiroshima atomic bombs every second (Cheng et al. 2020).

The rise in ocean temperatures has been accelerating significantly since the 1990s; since 1993 the rate of ocean warming has more than doubled (IPCC 2019). In 2019, the world's oceans were their warmest in recorded history. Oceans around Australia have warmed by more than 1°C since 1910. Marine heatwaves are becoming more intense and occurring more often, causing extensive and permanent damage to many marine ecosystems, including coral reefs (See CASE STUDY: Coral mortality), kelp forests and sea grass. (CSIRO and BoM 2020.)

Figure 3: Marine heatwaves are causing extensive damage to coral reefs.

CASE STUDY: EXTREME HEAT IN WESTERN SYDNEY

On 4 January 2020, Penrith was officially the hottest place on Earth at 48.9°C. Such temperatures are already pushing the limits of human endurance, and people in urban settings like Penrith may be regularly exposed to even higher temperatures than those officially recorded due to amplifying factors such as concrete and asphalt (Thompson 2020) - the 'urban heat island' effect. In particular, extreme heat endangers children, the elderly, people with existing health conditions and other vulnerable groups (Climate Council 2016).

Extreme heat in Sydney demonstrates how climate change can exacerbate existing socio-economic inequalities. Western Sydney experiences higher summer temperatures than suburbs nearer the coast. For example, over the 2019-20 summer, western Sydney recorded 37 days over 35°C compared to six in the east of the city (Amin 2020). This matches the marked socio-economic divide between Sydney's affluent east and the fast-growing western suburbs, with incomes, job opportunities, and access to education all split along the so-called "latte line" that divides the cities' eastern suburbs and north shore from the west (Gladstone 2018).

Very high temperatures in schools make it harder for students to concentrate, contributing to reduced learning outcomes (Pfautsch et al. 2020). Research from the University of Western Sydney revealed that for students in Sydney's western suburbs, extreme summer heat in schools is often compounded by the poor design of buildings, inadequate shade and surfaces that absorb much heat (Pfautsch et al. 2020).

Without far stronger action to address climate change and support communities to adapt to new extremes, we risk further entrenching inequalities.

On 4 January 2020, Penrith was officially the hottest place on Earth. Western Sydney is suffering more than eastern Sydney under climate change.

CASE STUDY: 2020 SIBERIAN HEATWAVE

In the first six months of 2020, an intense, persistent and widespread heatwave across Siberia broke temperature records, fuelled large fires, and thawed permafrost. Overall, temperatures for the region were more the 5°C above average from January to June. This extraordinary extreme heat event made global headlines when the Russian town of Verkhoyansk recorded a temperature of 38°C in June, likely the highest temperature ever recorded in the Arctic (Dunne 2020).

Also in June, satellite images detected signatures of "zombie fires", remnants from the previous season's record fires that had continued smouldering underground throughout winter in the carbon-rich peat and had flared up again with warm temperatures. Pyrocumulonimbus clouds, or "fire thunderstorms" – a rare phenomenon anywhere and especially unusual at such high latitudes – were also detected (Deacon 2020).

In July, an attribution study concluded that the 2020 Siberian heatwave would have been "almost impossible" in the absence of climate change, showing with high confidence that the event "was made at least 600 times more likely as a result of human-induced climate change" (Ciavarella et al. 2020).

Siberia is one region where global warming has a particularly devastating effect, not only on local ecosystems and communities, but also on the climate system as a whole as the release of greenhouse gases through thawing permafrost and large fires contributes to further warming.

CASE STUDY: CORAL MORTALITY

Just as we are experiencing more frequent and severe heatwaves on land, climate change is also driving deadly marine heatwaves that are devastating ocean ecosystems.

There can be no more striking illustration of the frightening pace of climate change and its profound impacts on living systems than the plight of Australia's Great Barrier Reef (GBR). The GBR is the world's largest coral reef system, and in its current form is about 8,000 years old. Between 1995 and 2017 – a mere blink of an eye compared to its age – the GBR lost more than half its hard corals due to warmer seas driven by the greenhouse gas emissions from burning coal, oil and gas (Dietzel et al. 2020).

Back-to-back bleaching events in 2016 and 2017 damaged two thirds of the reef. In March 2020, as Australia was scrambling to contain the COVID-19 outbreak, news emerged of the third mass bleaching event within five years (GBRMPA 2020). The marine heatwave that caused widespread bleaching of the GBR in 2016 was made 175 times more likely due to climate change (King et al. 2016).

In its Special Report on 1.5°C, the Intergovernmental Panel on Climate Change (IPCC) projected that even if the global average temperature rise is held to 1.5°C, coral reefs will decline by a further 70-90 percent. At 2°C, tropical reef-building corals are expected to "mostly disappear", with the loss of more than 99% of the corals.

While we often communicate the price of these losses in terms of the estimated $6 billion value of the GBR to the Australian economy and the 64,000 jobs it supports (Deloitte Access Economics 2017), in reality these numbers do little to convey the gravity of the crisis unfolding before our eyes. As Chief Councillor Tim Flannery notes in his 2020 book *The Climate Cure:*

> *"[Coral] reefs are home to the greatest biodiversity in the oceans, and their loss would reverberate throughout Earth's ecosystems, both marine and terrestrial. And the human impacts would be immense. Entire nations (the coral atoll nations) depend upon them for food and protection against erosion. Many consequences of the loss of coral reefs are probably not conceivable until they eventuate."*

In 2020 the International Union for Conservation of Nature, advisory body to the UNESCO World Heritage Committee, escalated its conservation outlook for the Great Barrier Reef from "significant concern" to "critical" (IUCN 2020).

There's no more striking illustration of the frightening pace of climate change and its profound impacts on living systems than the plight of the Great Barrier Reef.

2.2 Intense rainfall

A warmer atmosphere can hold more water vapour – approximately 7 percent more for every degree of warming (Trenberth 2011). A warmer and wetter atmosphere also provides more energy for weather systems that generate intense precipitation (rain, snow, hail). So, while climate change may mean only a modest increase in the overall amount of precipitation globally – limited by the moisture holding capacity of the atmosphere – it's leading to a marked increase in the heaviest and most damaging storm events. In other words, more of our rain is falling in fewer extreme downpours, often interspersed with prolonged dry periods. If the current trend continues, the frequency of today's most intense precipitation events is likely to almost double with each degree of further warming (Myhre et al. 2019).

The pattern of more intense, heavy rainfall events is well established in Australia. In recent decades, the intensity of short-duration extreme rainfall events, which are often associated with flash flooding, has increased by around 10 percent in some regions, with particularly large increases observed in the north. These short-duration events are often associated with thunderstorms, cyclones, and east coast lows, and there has been an observed increase in the rainfall associated with these systems since 1979 (CSIRO and BoM 2020).

In January/February 2019, heavy rainfall caused widespread flooding across north and far north Queensland, affecting more than half of the state. It was one of the worst disasters in the region's history. The total social and economic costs were estimated at $5.68 billion, or around 14 percent of the region's annual economic output. This included damage to homes and infrastructure, impacts on health and wellbeing, and the loss of half a million cattle (Deloitte Access Economics 2017).

Australia is experiencing more intense, heavy rainfall. In 2019, heavy rainfall caused widespread flooding affecting more than half of Queensland – one of the worst disasters in the region's history.

CASE STUDY: 2020 ASIAN MONSOON FLOODS

Billions of people across the populous countries of south and east Asia depend upon the Indian and East Asian monsoons. While seasonal monsoon rains are fundamental to food and water security, they can also cause catastrophic flooding. Consistent with shifting rainfall patterns globally, the Indian monsoon is becoming more extreme, with prolonged dry spells punctuated by intense downpours (Singh 2014). A recent review of current knowledge on how climate change is affecting monsoons globally concluded with high confidence that climate change "has already caused a significant rise in the intensity and frequency of extreme rainfall events in all monsoon regions" (Wang et al. 2020).

India, Bangladesh, Nepal, China, and Pakistan all suffered heavy losses in severe floods in 2020 following intense monsoon rains. The worst flooding along the Yangtze River for decades occurred in June, killing hundreds of people in China, destroying croplands, and testing the limits of the giant Three Gorges Dam (Patel 2020). In July, flooding in India (Assam) and Nepal killed at least 200 people and displaced millions, hindering efforts to slow the spread of COVID-19 (Ellis-Petersen 2020). In Bangladesh, no stranger to floods, the worst monsoon flooding for many years left around a third of the country submerged (Hasina 2020). Pakistan set a new monthly rainfall record in August, and the military was deployed to rescue people from flooded areas of Karachi (Qayum and Dilawar 2020).

Figure 4: The Indian monsoon is becoming more extreme.

2.3 Storms and cyclones

Tropical cyclones, known as hurricanes in the north Atlantic and northeast Pacific, typhoons in the northwest Pacific, and cyclones in the South Pacific and Indian Oceans, are among the most destructive extreme weather events.

Many Pacific Island Countries, including Fiji, Vanuatu, Solomon Islands and Tonga, lie within the South Pacific cyclone basin. In recent years, a run of extraordinarily damaging cyclones in the Pacific has taken a heavy toll on local economies. In 2015, Category Five Cyclone Pam, then the strongest South Pacific cyclone on record,[3] caused damages equivalent to 64 percent of Vanuatu's Gross Domestic Product (GDP). A year later, Cyclone Winston, an even stronger cyclone, devastated Fiji with damages amounting to 31 percent of GDP. In 2018, Cyclone Gita hit Tonga, causing losses equivalent to 38 percent of GDP. Most recently, in 2020, Cyclone Harold – the second strongest cyclone to hit Vanuatu after Cyclone Pam – severely affected Vanuatu, Solomon Islands, Fiji and Tonga, compounding the economic impact of COVID-19 (Taylor 2020.) In Australia, Cyclone Yasi in 2011 and Cyclone Debbie in 2017 remain two of our most costly disasters.

Climate change is affecting the conditions in which tropical cyclones form and develop. Climate change is linked to many different aspects of cyclone formation and behaviour, including how often they form, maximum windspeed and amount of rainfall (IPCC 2012), the speed at which a system intensifies (Bhatia et al. 2019), the speed at which a system moves (known as translation speed) (Kossin 2018), how much strength is retained after reaching land (Li and Chakraborty 2020), the duration of cyclone seasons, and the geographic range of tropical cyclones (Kossin et al. 2014).

Cyclones form most readily when there is a very warm ocean surface and a strong temperature gradient through the atmosphere – i.e. a big difference in the temperature of the air at the surface and the air higher up. A warming climate means that the temperature gradient is likely to decrease, so the conditions in which cyclones form may occur less often. This means that the overall number of cyclones that form will likely decrease. However, rising ocean surface temperatures and a warmer, wetter atmosphere provide a larger source of energy for cyclones to draw on once they do form. It is thus likely that tropical cyclones will become more intense with climate change in terms of maximum wind speed and the amount of rainfall they produce (IPCC 2012). For example, the amount of rainfall in two of 2017's most destructive hurricanes – Irma and Maria – was likely six percent and nine percent higher, respectively, compared to a world without climate change (Patricola and Wehner 2019).

In summary, there are likely to be fewer cyclones overall but a higher number of those that do form will likely be more intense and destructive.

3 Measured in terms of peak 10-minute sustained windspeed.

Figure 5: Typhoon Goni, which struck the Philippines in November 2020, was the strongest landfalling cyclone on record.

Until recently, with the exception of the North Atlantic basin where records show a clear increase in the intensity of cyclones over recent decades,[4] there has not been enough historical data of sufficient quality to discern clear real-world trends in cyclone activity. However, in 2020 an analysis of nearly 40 years of satellite imagery concluded that maximum wind speeds are getting stronger for cyclones in almost every region where they form, affirming what models had long predicted (Kossin et al. 2020).

As well as reaching higher intensity, it is also possible that a warming climate is enabling cyclones to strengthen more quickly (Bhatia et al. 2019). "Rapid intensification" is a term used to describe the dramatic strengthening of cyclones over a short period of time. The US National Hurricane Center defines this as an increase in wind strength of at least 35 mph (56 kmh) within 24 hours. In the 2020 North Atlantic hurricane season (see CASE STUDY: 2020 North Atlantic hurricane season) a record-equalling ten storms exhibited rapid intensification. Two of 2020's record number of North Atlantic hurricanes, Eta and Iota, strengthened by 80mph (129 kmh) in 24 hours, an intensification rate observed only eight times before and never so late in the season. In the early 1980s, the chance of a hurricane rapidly intensifying were 1-in-100. Those odds have now shortened to less than 1-in-20 (Bhatia et al. 2018). Rapid intensification can lead to disastrous outcomes, as coastal communities may not be given adequate warning to prepare for an intense cyclone (Bhatia et al. 2019).

We should prepare for more intense and destructive cyclones due to climate change.

4 Since 1980, the number of North Atlantic hurricanes with winds stronger than 200 km/h have doubled, and those with winds stronger than 250 km/h have tripled (Rahmstorf et al. 2018).

Based on recent observations, it is also possible that cyclones are staying stronger after making landfall. A cyclone, which derives its strength from warm ocean surfaces, begins to lose strength on reaching land. However, climate change may slow down this effect, thus allowing the cyclone to wreak more destruction and reach communities further inland (Li and Chakraborty 2020). It thus appears that on a warming planet, cyclones are both powering up more quickly and winding down more gradually.

Lastly, there is evidence that cyclones are moving more slowly. That is the rate at which a system tracks across the ocean and land, known as translation speed as opposed to its maximum wind speed, is decreasing. On average, it appears that translation speed decreased by 10 percent between 1949 and 2016 (Kossin 2018). This may be the result of a slowdown in atmospheric circulation (Zhang et al. 2020). Slow-moving cyclones, such as Hurricane Maria in 2017, can be hugely destructive, dumping immense amounts of rain over a small area, while also sustaining damaging windspeeds for a longer period (Resnick 2017).

While there may be differences in the state of knowledge about these various trends and their links to climate change, there is little doubt that, overall, climate change is increasing the destructive power of tropical cyclones. This is especially true when considering other impacts of climate change that, while not directly affecting cyclone behaviour, are nonetheless increasing the dangers. For example, cyclones are now riding upon higher sea levels, meaning that storm surges – often the deadliest aspect of a cyclone – are higher and penetrate further inland than they would otherwise (Climate Council 2017). Climate change is also damaging many natural coastal defences, including coral reefs and mangroves, which leave communities and infrastructure more exposed to the destructive power of cyclones.

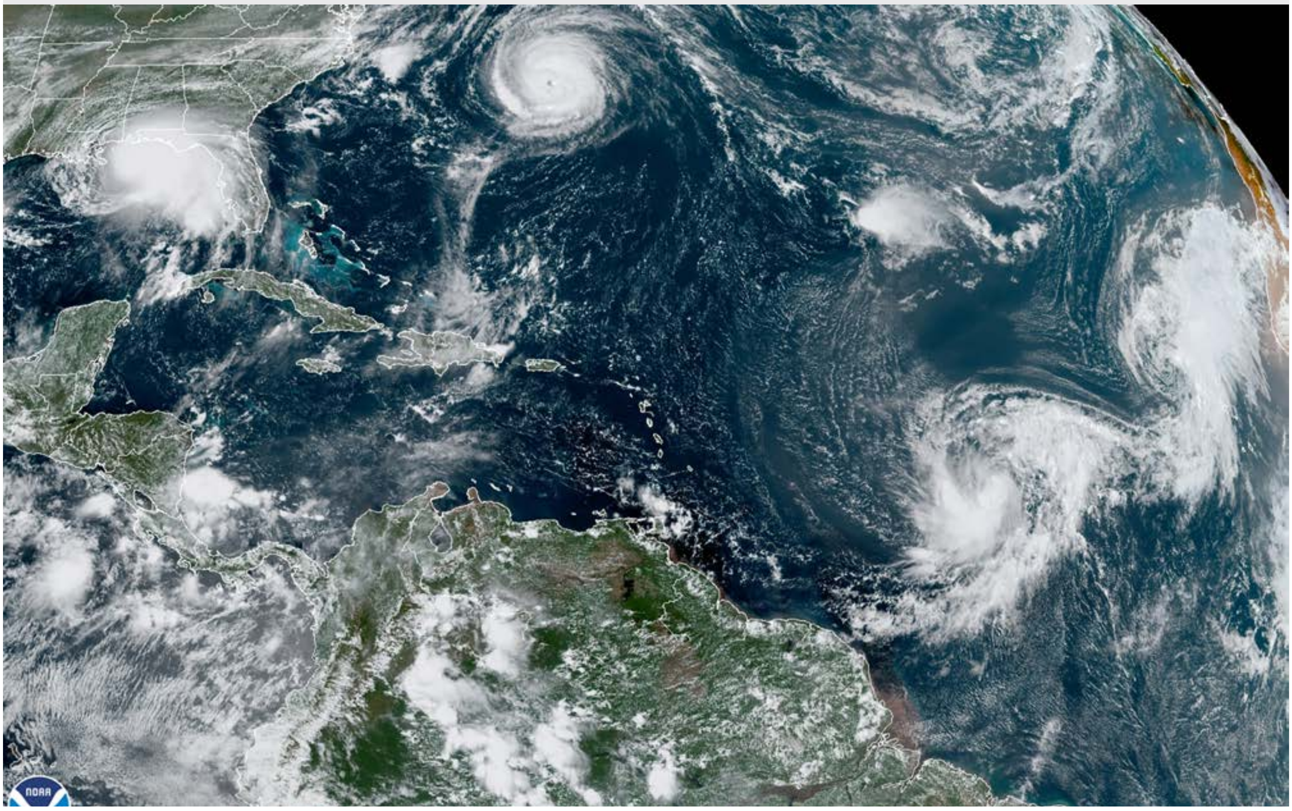
CASE STUDY: 2020 NORTH ATLANTIC HURRICANE SEASON

While the US West Coast burned, the East Coast, Caribbean and Central America were pummelled by a record-breaking Atlantic hurricane season. Between May and November, the region recorded 30 named tropical storms, including 13 hurricanes and six major hurricanes – more than double the number experienced during an average season (WMO 2020). Twelve named storms hit the US mainland, beating the previous record of nine. For only the second time, the US National Hurricane Centre had to use names from the Greek alphabet, as the standard list of alphabetical names had been exhausted.

The most destructive storm of the season was Hurricane Eta, which made landfall in Nicaragua on 3 November as a category four storm. Eta moved very slowly, lingering for three days over Central America, producing immense amounts of rain and killing at least 215 people. Just two weeks later, the last and strongest storm of the season, Hurricane Iota, rapidly intensified into a category five system before hitting Colombia, Nicaragua, Honduras and other countries of Central America, including areas already hit two weeks earlier by Hurricane Eta (Masters 2020).

The damage from this year's unprecedented Atlantic hurricane season is likely to increase pressure on people in Central America to migrate out of harm's way, including across borders (Palencia and Lopez 2020).

Figure 6: September 2020 saw five tropical cyclones churning in the Atlantic baisin at the same time.



2.4 Fire

In 2019-20, astonishing fire seasons across several continents, from Australia to the Amazon, Siberia and the US West Coast, ushered in a new and dangerous era of megafires. Tens of millions of hectares of forest were razed by fire, hundreds of lives and thousands of homes lost, billions of animals killed, and critical ecosystems pushed to or over the brink.

For a full account of Australia's Black Summer fires, see Climate Council's report: **Summer of Crisis**

In terms of the size of area burned, the US West Coast fires broke almost every conceivable record for the region, eclipsing California's then record-breaking and deadly 2018 season (See CASE STUDY: 2020 US West Coast fires). Australia's Black Summer of 2019-20 was similarly unprecedented in its scale and harm with 21 percent or more of eastern Australian temperate broadleaf and mixed forests burned. Typically, less than 2-3 percent of these forests burns annually, even during more extreme fire seasons (Boer et al. 2020). Large parts of the Gondwana rainforest – a living link to the former Gondwana supercontinent and a wellspring of unique Australian flora and fauna – were razed. This unique and ancient ecosystem was previously considered too wet to burn. Further south, the Gospers Mountain fire became the largest forest fire ever recorded in Australia, burning through more than half a million hectares including a large part of Wollemi National Park. A staggering 81% of the nearby Blue Mountains World Heritage Area also burned. Around three billion animals are likely to have perished or been displaced by the Black Summer fires (WWF 2020), 33 human lives were lost directly to the fires, and an estimated 429 more from the smoke that blanketed large parts of the country (Johnson et al. 2020).[5]

Higher temperatures and shifting rainfall patterns are driving increased fire risk in many of the world's great forest and grassland ecosystems, from the boreal zone to the tropics.

In Australia, extremely hot, dry conditions, underpinned by years of reduced rainfall and a severe drought, set the scene for the Black Summer fires (Hughes et al. 2020). Extreme fire weather and the length of the fire season across large parts of Australia have increased since the 1950s (CSIRO and BoM 2020). In some regions of southern Australia there is an increasing risk of more extreme bushfires that can generate thunderstorms within their smoke plumes (CSIRO and BoM 2020). Such fires are very dangerous and unpredictable. Lightning strikes from these pyrocumulonimbus clouds can spawn new fires well ahead of the main fire front.

> *"Climate change has pushed Australia into a new era of unprecedented bushfire risk, and our governments have underestimated the threat." Greg Mullins (2020)*

5 Research by Johnson et al. (2020) estimated the smoke-related health costs of the Black Summer fires at AUD$1.95 billion, driven largely by "an estimated 429 smoke-related premature deaths in addition to 3,230 hospital admissions for cardiovascular and respiratory disorders and 1,523 emergency attendances for asthma".

CASE STUDY: 2020 US WEST COAST FIRES

Australia was not the only place to experience truly unprecedented fires in 2019-20.

By the end of 2020, fires had burned more than four million acres (1.6 million hectares) of California, more than double the record set in 2018 (CalFire 2020). Five of the six largest fires on record for the state occurred in 2020. California recorded its first "gigafire" in modern history – a fire of over a million acres (Milman and Ho 2020).

> *"We have never seen this amount of uncontained fire across the state... This will not be a one-time event. Unfortunately, it is the bellwether of the future. We're feeling the acute impacts of climate change." Oregon Governor Kate Brown*

Other states also suffered one of their most destructive fires seasons. In Oregon, fires burned over a million acres (400,000 hectares), more than twice the average for a season and at one point threatened Portland's suburbs; prompting mass evacuations (McGrath 2020). Washington state recorded more fires than in any other year (O'Sullivan 2020). Colorado experienced its largest single fire on record (Lytle 2020).

The parallels between the 2020 US West Coast fires and Australia's Black Summer of 2019-20 are hard to miss. Both were unequivocally driven by climate change, following long dry periods and record heat. Both set records for the largest fires ever recorded in each country. Both left large population centres blanketed in smoke, creating eery images of national icons like the Sydney Harbour Bridge and San Francisco's Golden Gate Bridge bathed in an orange hue. Events once considered very rare, including fire tornados and pyrocumulonimbus clouds, were observed many times. Both exposed failures of national leadership and tensions between state and federal authorities over climate inaction. Both spawned renewed interest in Indigenous land and fire management, and recognition that supporting the leadership of First Nations people is an essential part of responding to the climate crisis (Commonwealth of Australia 2020, Singh 2020).

We have ushered in a new and dangerous era of megafires.

2.5 Drought

Climate change has likely brought an increase in the frequency and/or severity of drought in some regions due to shifting rainfall patterns and higher temperatures. The Mediterranean, western US, West Africa and northeast China are among the regions to have observed a reduction in rainfall over recent decades (IPCC 2013). Based on the IPCC's Special Report on 1.5°C (2018), twice as many people worldwide would be exposed to water scarcity at 2°C of warming compared to 1.5°C. The Mediterranean and Caribbean would be among the areas hit particularly hard.

Climate change has already had a significant impact on rainfall over parts of Australia, in particular the southeast and southwest. In the southeast, rainfall during the cool season (April to October) has declined by 12 percent since the late 1990s. In the southwest rainfall during the cool season (April to October) has declined by around 16 percent since 1970, and by 20 percent between May and July. A continued decrease in cool season rainfall is expected across many regions of southern and eastern Australia (CSIRO and BoM 2020).

Figure 7: Climate change has likely brought an increase in the frequency and/or severity of drought in some regions.

CASE STUDY: FLASH DROUGHT

In mid-2019 much of inland New South Wales found itself in what meteorologists have started terming a 'flash drought' (Doyle 2020). A flash drought is characterised by the sudden onset and rapid intensification of drought conditions, over a period of weeks or months. A similar situation occurred along much of Australia's east coast during the last months of 2017 and into 2018.

Flash droughts occur when there is a very fast reduction in soil moisture, typically resulting from a lack of rainfall alongside factors that increase evaporation including high temperatures, low humidity, and strong winds (Otkin et al. 2018). Acting together, these factors can quickly turn a manageable situation into severe drought conditions.

The impacts of flash droughts can be severe, as the rapid onset can mean little time for farmers to prepare and for common coping mechanisms to be deployed (Nguyen 2019). While existing dry conditions naturally leave an area at greater risk, flash droughts can even occur when prior conditions did not appear conducive to drought development (Christian 2019). Recent research has aimed at better predicting flash droughts (Nguyen et al. 2019, Pendergrass et al. 2020).

Scientists have had to coin a new phrase 'flash drought' to capture the sudden onset of such events that can catch farmers and communities unprepared.

BOX 1: COMPOUND DISASTERS

Climate change, by increasing the frequency and/or severity of destructive weather events as well as the background conditions such as average temperature and sea level, is increasing the risk of 'compound extremes': instances where multiple destructive events or elements occur at the same time or in close succession, exacerbating one another such that the overall impact is worse than if each had occurred in isolation.

Events making up a compound extreme may be similar in nature. For example, two tropical cyclones hitting the same area in close succession, as for communities in Central America that were hit by both Cyclone Eta and Iota within the span of only two weeks (See CASE STUDY: 2020 North Atlantic hurricane season). In other instances, events may be different in nature. For example, heavy rainfall falling on a landscape charred by bushfires may mean a high likelihood of landslides (Rengers et al. 2020).

Compound extremes may also be caused by a combination of events or elements that are not in themselves extreme, but when combined prove very destructive - for example, a moderate storm combined with very high tide. Another example is a series of coastal erosion events that occur in quick succession, with little time in between for the coast to be replenished, such as happened along parts of the NSW coast in July 2020 (Hannam 2020).

Compound extremes can inflict immense human suffering, economic costs and environmental damage. Climate-related disasters may also exacerbate non-climate-related challenges and vice versa. For example, when Cyclone Harold – the strongest cyclone to hit Vanuatu since record-breaking Cyclone Pam in 2015 – caused widespread destruction, urgent relief efforts had to be managed alongside necessary measures to prevent the spread of COVID-19 (Masivei 2020, Pringle 2020).

Figure 8: Vanuatu and other Pacific Island Countries had to deal with the impacts of Cyclone Harold and COVID-19 simultaneously.

3. Abrupt, nonlinear extreme events

Many changes in the climate system appear as smooth curves in which the response of the system is proportional to the level of pressure applied – that is, straight-forward cause-effect logic. An example is the rise in global average surface temperature in response to human emission of greenhouse gases. However, nonlinear changes can occur when a small increase in pressure on the system reaches a critical level. The result is often an unexpectedly large and, in some cases, irreversible change in the system.

Features of the Earth System that can exhibit abrupt, nonlinear, and and/or irreversible behaviour are called 'tipping elements', and the level of the external pressure required to trigger the response is often called the 'tipping point' (Lenton et al. 2008). Some, but not all, extreme weather events can show tipping point behaviour when a critical level of pressure - e.g., rising temperature, rainfall reduction, or both - trigger a surprising large, abrupt response. Below we describe two recent Australian examples of extreme events that display tipping point/abrupt change behaviour.

Figure 9: NSW Farmer Rob Lee, New Year's Eve 2019. The Black Summer was an esxample of an extreme event that can be explained by tipping point behaviour.

3.1 Coral reefs

(See also CASE STUDY: Coral mortality). Coral bleaching is a classic example of a tipping point being transgressed. Corals exist in a fairly narrow band of water temperature and have thrived in the relatively stable climatic conditions of the Holocene, the 11,700-year epoch up to about 1950. Since then, surface ocean temperatures have risen steadily towards the upper limit within which corals can thrive. There were virtually no bleaching events up until the 1990s, when the Great Barrier Reef (GBR) suffered significant bleaching in 1998 and 2002 (Hughes et al. 2018). This was a warning sign that coral reefs were approaching their tolerable temperature limit.

Not surprisingly, even more severe bleaching followed as temperatures continued to rise. As described earlier, extensive and damaging mass bleaching events occurred on the GBR in 2016 and 2017, and these were followed by another such event in March 2020. The latest event was the first time that significant bleaching occurred along the entire 2,300-km length of the GBR. The result of these increasingly frequent and severe bleaching events was the loss of about half of all hard corals on the GBR. When the critical temperature was breached, the corals did not just suffer a proportional increase in bleaching but suffered mass bleaching, typical of tipping point/abrupt change behaviour.

Projections from the IPCC Special Report on 1.5°C warming (IPCC 2018) warn that the majority of the world's coral reefs would be eliminated by a 1.5°C temperature and virtually all – more than 99% - would be eliminated by a 2°C rise. The band of global average temperature rise between 1°C and 2°C above pre-industrial thus represents a tipping point for coral reefs, with the precise temperature depending on the local conditions of the reef and short-term climate variability. Given the approximately 10,000-year history of coral reefs in the Holocene, a 50-year period (2000-2050) and a narrow temperature window (1°C-2°C above pre-industrial) represent a very sharp tipping point.

Bleaching of coral reefs would be largely irreversible in human timeframes given that global average temperature will remain at elevated levels for centuries even after we finally eliminate human emissions of greenhouse gases (Collins et al. 2013).

3.2 2019-20 bushfire season

(See also 2.4 Fire). The massive bushfires that burned much of eastern Australia during the 2019-20 summer are another example of an extreme event that can be explained by tipping point behaviour. Figure 10 below shows the annual burned area of various forest types.

For Australian temperate broad-leafed and mixed forests, which cover about 27 million hectares in eastern Australia, the 2019-20 fires were unprecedented, both for Australia and globally. The fires burned about 5.8 million hectares or about 21% of the entire area of the biome when typically, about 2-3 percent of these forests burn in a season. This extreme event clearly shows abrupt and unprecedented change behaviour, and the analysis of the antecedent climatic conditions strongly supports the conclusion that a tipping point had been crossed. In fact, Boer et al. (2020) describe the highly nonlinear relationship between fires and antecedent climate conditions as an ‘on-off’ switch, another description of tipping point-abrupt change behaviour.

In the 2019-20 bushfires, a tipping point was likely crossed, with the burning of one fifth of Australia’s temperate broad-leafed forests.

Figure 10: Annual burned area percentages for continental forest biomes (2000-2019). **Source:** Boer et al. 2020.

The boxes represent the 25th to 75th percentiles, with the line in the middle the median. The vertical lines extend to 1.5 times this middle 50%, and the dots are outliers. The numbers connote different biome types from a classification scheme used by WWF: 1. tropical and subtropical moist broadleaf forests | 2. tropical and subtropical dry broadleaf forests | 3. tropical and subtropical coniferous forests | 4. temperate broadleaf and mixed forests | 5. temperate conifer forests | 6. boreal forests/ taiga | 12. Mediterranean forests, woodlands and scrub. The red horizontal line indicates the area of Australia's temperate broadleaf and mixed forest that burned in 2019-20.

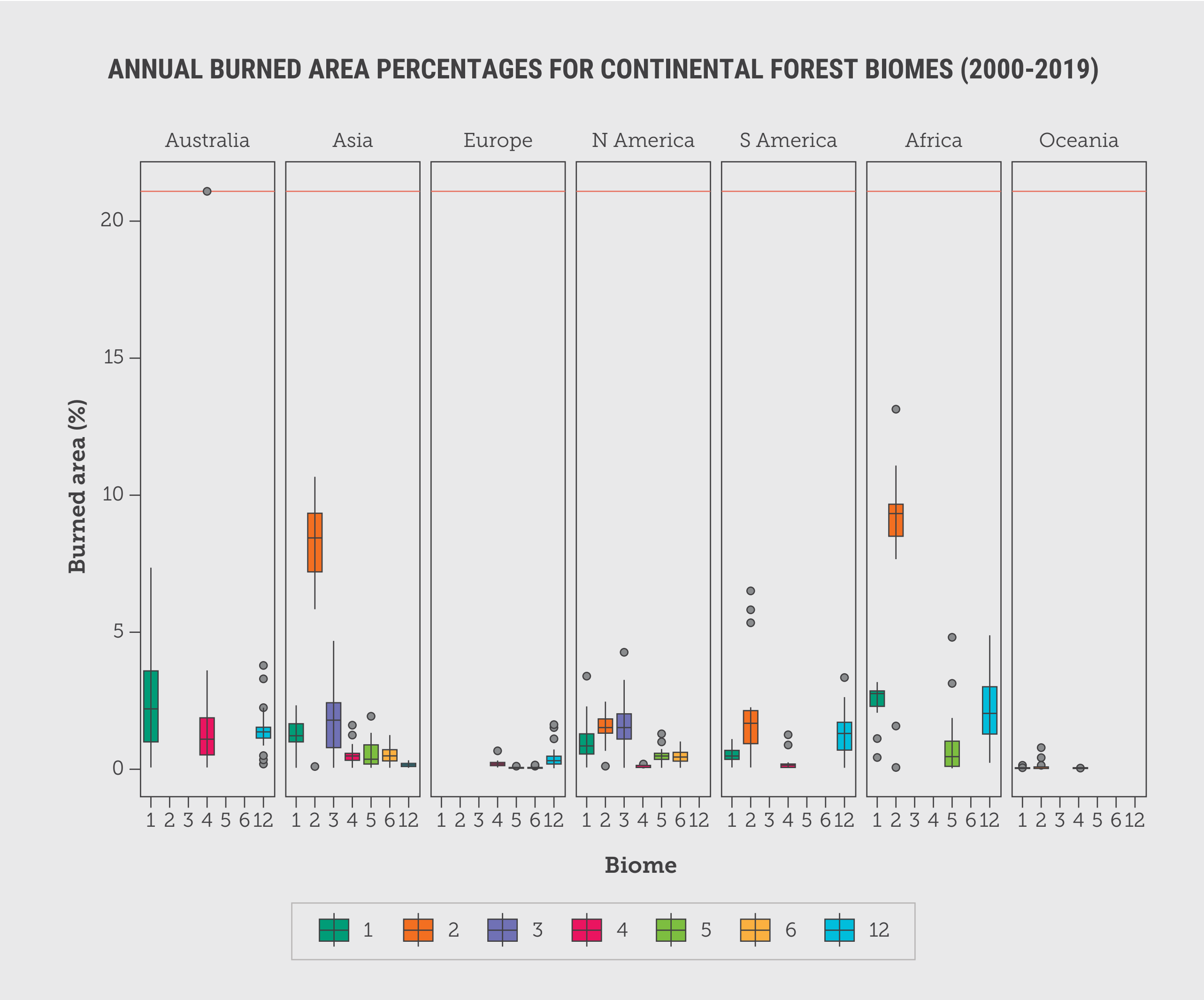
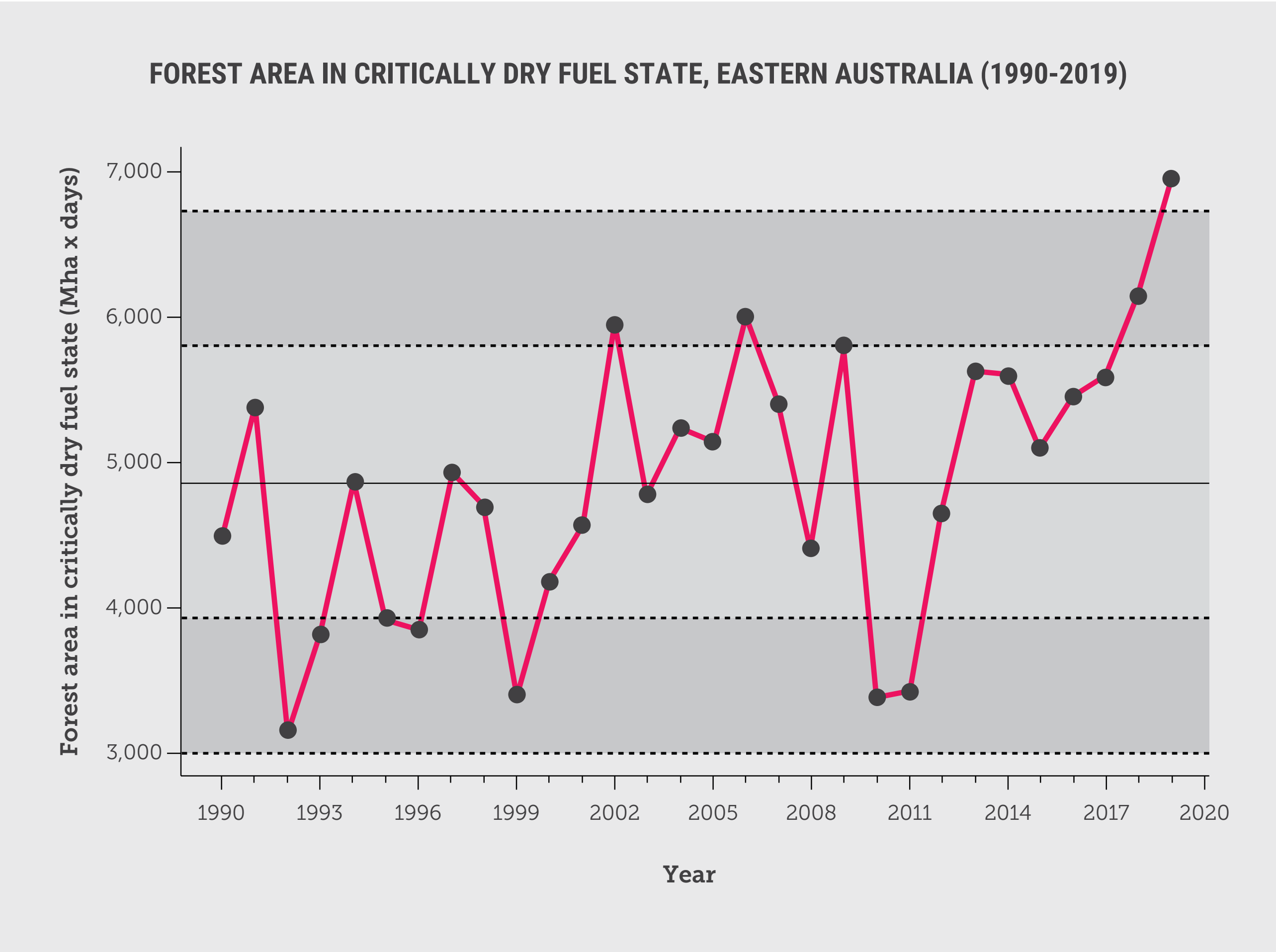


Figure 11 below shows the other factor in the bushfire tipping point - the changes in forest conditions for the 20 years leading up to the 2019-20 bushfire disaster. Up until 2017 the area of forest in a critically dry condition - caused by a combination of low rainfall and high temperature – remained within +/- one standard deviation of the average state (30-year mean) and only occasionally fell to -2 standard deviations. However, over the past few years, the area of forest in a critically dry fuel state has risen rapidly, breaching the +2 standard deviations from the mean in 2019. This can be interpreted as the crossing of a critical tipping point in 2019 in terms of extreme fire conditions, resulting in very violent fires and a massive area burnt.

Figure 11: Forest area in critically dry fuel state, eastern Australia (1990-2019). **Source:** Boer et al. (2020).



4. The cost of inaction – Where we are now compared to ten years ago

We are paying dearly for past inaction, not only in terms of the extreme weather we've already experienced but also for the lost opportunity to prevent much worse.

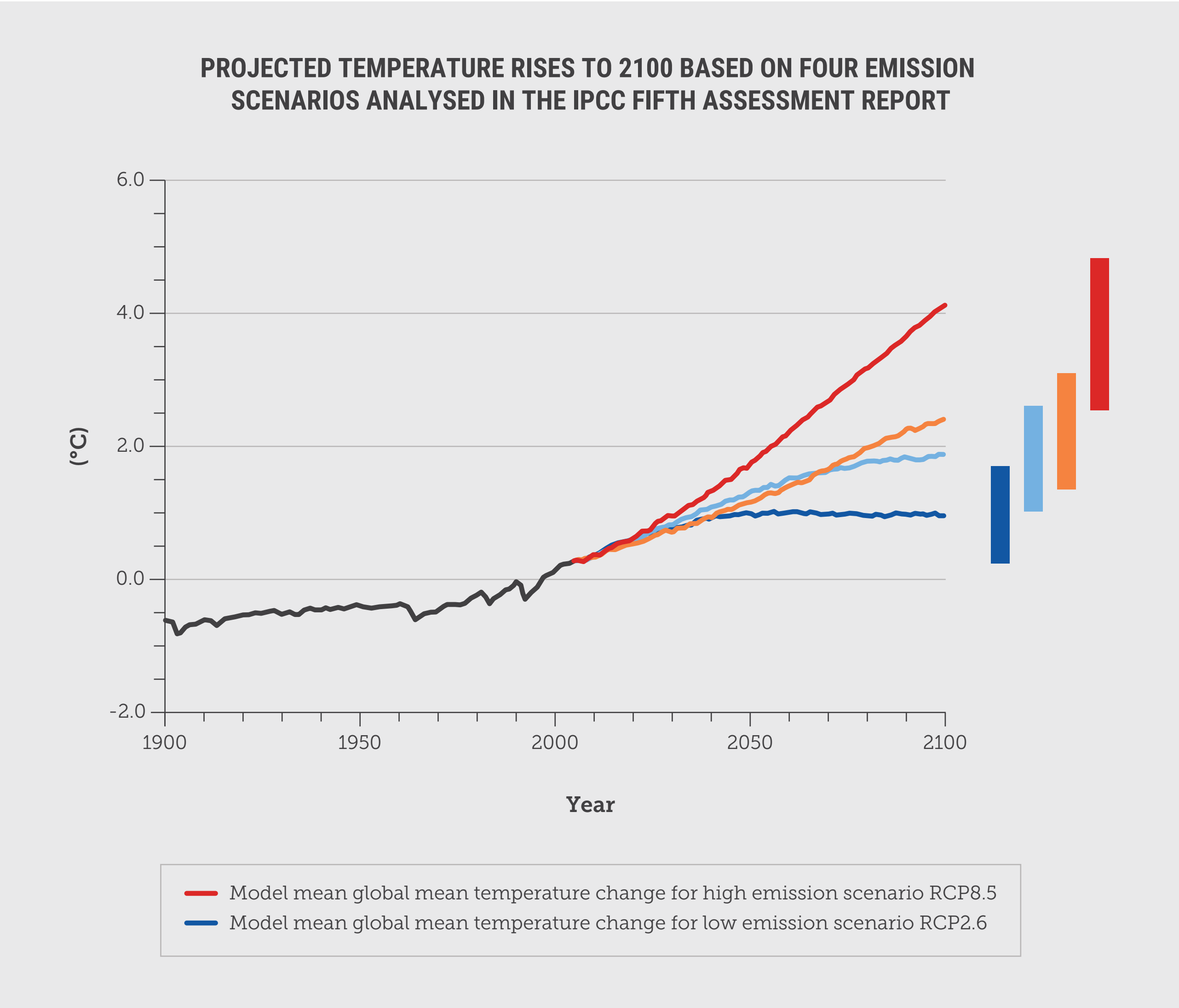
We are paying dearly for past inaction, not only in terms of the extreme weather we're experiencing but also for the lost opportunity to prevent worse.

Based on the momentum in the climate system, primarily due to the massive amount of heat that is being stored in the ocean, and the fact that it is now impossible to achieve what science said we should - net-zero emissions within a decade - there is worse to come. Figure 12 shows the temperature trajectories for the four IPCC emission scenarios, from RCP2.6 (the lowest) to RCP8.5 (the highest) from 2005 to 2100. There is very little difference in the temperature trajectories to at least 2025 and no trajectory begins to flatten until 2040-2050. As stated in the IPCC report: "Temperature increases are almost the same for all the RCP scenarios during the first two decades after 2005" (Collins et al. 2013).

Emissions have continued to climb through the 2010-2019 decade. Based on the range of emission scenarios beginning from 2020 onwards, we cannot expect a significant difference in the rise in global average temperature until at least 2040. This implies that worsening extreme weather is locked in for the next decade at least, and very likely until 2040. Looking backwards, the extreme weather we will experience in 2030 was locked in by 2010 regardless of the emission trajectory we followed over the past decade (Collins et al.2013).

The message from this analysis is clear: climate inaction is costly us dearly. Such inaction is critical because it significantly reduces our chances of staying under the Paris temperature targets and it pushes back the likely time when the climate is eventually stabilised, now around mid-century at the earliest.

Figure 12: Projected temperature rises to 2100 based on four emission scenarios analysed in the IPCC Fifth Assessment Report. Key: Dark blue: RCP2.6; light blue: RCP4.5; orange: RCP6.0; red: RCP8.5. **Source:** Collins et al. (2013).



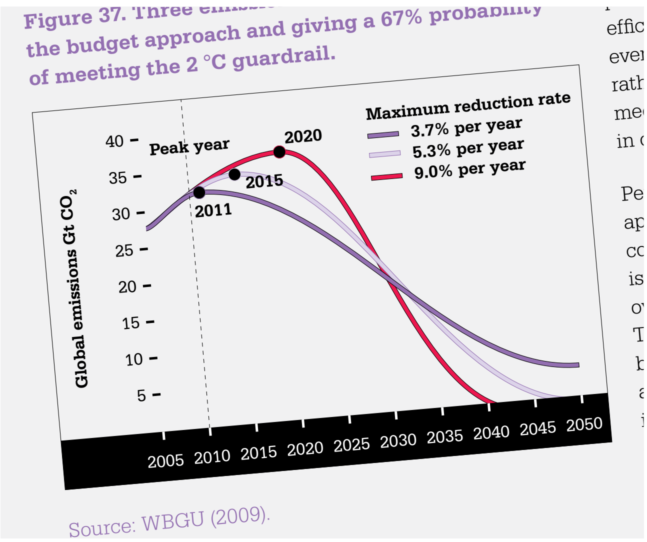
Australians are paying the price for countries ‘including Australia’ not cutting emissions fast enough, or deep enough.

In 2011, the newly formed Climate Commission (the forerunner of the Climate Council) published its first Critical Decade report, looking ahead towards 2020. A key feature of that report – and one that gave it the title – was the analysis of emissions trajectories that were required to have a 67% probability of staying under a 2°C target (Figure 13).

Two startling things stand out. First, we clearly knew back in 2011 how important the peaking date of our emission trajectory was as well as the level of emissions at that peak. Had our emissions peaked back in 2011, we would have been able to reduce our emissions at a maximum rate of 3.7% per year and avoid the worst climate impacts. Climate inaction has delayed that peak for at least a decade and now requires a maximum 9% emissions reduction per year as well as reaching net zero emissions no later than 2040. Even doing that will only keep temperatures under 2°C, not the lower and safer 1.5°C Paris target.

Second, note the magnitude of the emissions assumed in the three trajectories of Figure 13. It was assumed that by 2020, emissions would have peaked well under 40 Gt CO_2, possibly around 37 Gt CO_2, and fallen thereafter. In reality, global emissions were just under 43 Gt CO_2 in 2019 (Friedlingstein et al. 2019), significantly higher than the value assumed in the 2009 analysis described in Figure 13. This is important because Figure 13 is based on a carbon budget approach, in which cumulative emissions are the key indicator. So, peaking at a higher rate of emissions means that the subsequent emission reduction curves must be even steeper.

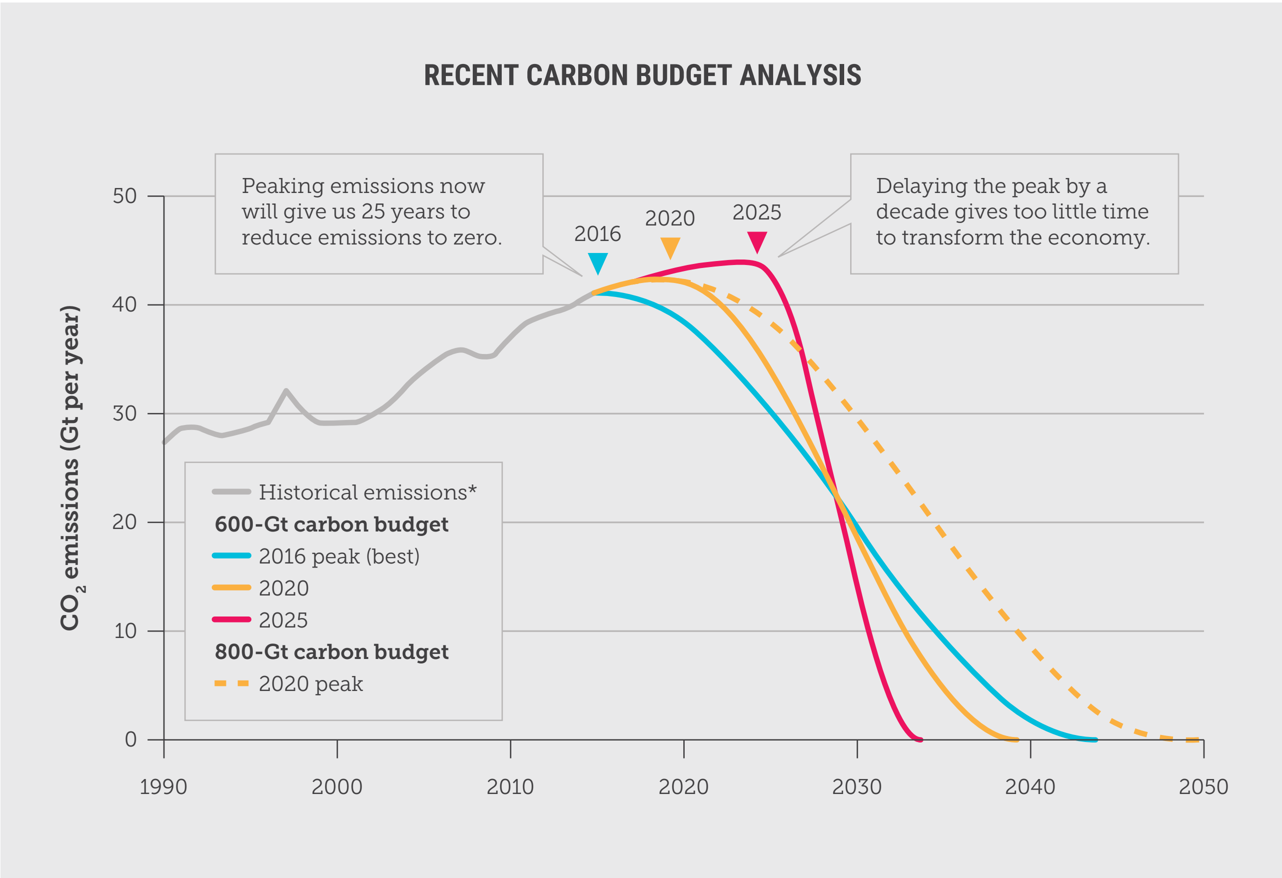
Figure 13: From the 2011 Climate Commission ‘Critical Decade’ report.



Application of the carbon budget approach has evolved since 2009 and more recent analyses have produced a somewhat more generous budget for a given temperature target than that used for Figure 13. Nevertheless, the decade of inaction has still cost us dearly. A more recent analysis of the carbon budgets (Figure 14) suggests that if emissions peak in 2020 – and the COVID-driven reduction in emissions gives us a chance to do that – then we might have a chance at keeping temperature rise below 2°C. However, if emissions bounce back to pre-COVID levels (of around 43 Gt CO_2 per annum) until 2025, then we face the impossible task of completely decarbonising our economies within a single decade.

In summary, inaction and delay are deadly. Had we started emission reductions a decade ago, we would be in good shape to stay under the 2°C upper and more dangerous target and may have had a chance at meeting the lower and safer 1.5°C target. Now, after a decade of inaction, we are in a climate emergency. We will miss 1.5°C (without overshoot) and we face a daunting task to keep temperature rise below 2°C. One more decade of inaction or weak action and the 2°C will likely be missed or, at the least, be extremely difficult to achieve.

Figure 14: Recent analysis of the remaining global carbon budget for keeping warming well below 2°C. Stretching the budget from 600 gigatonnes (Gt) to 800 Gt buys another 10 years, but at greater risk of exceeding the temperature limit. Figueres et al. 2017.



BOX 2: HITTING HOME – INTENSIFYING DISASTERS AND CASCADING IMPACTS

Contributed by Dr Robert Glasser, former Special Representative of the UN Secretary-General for Disaster Risk Reduction and Head of the UN Office for Disaster Risk Reduction.

It's not surprising, in the wake of *Black Summer's* unprecedented devastation, that much of the climate change discussion in Australia has focused on our growing national vulnerability to climate hazards like floods, drought and bushfires. However, the unfolding regional and global impacts of climate change will also profoundly affect our social, economic and political well-being and even undermine our national security.

We live in the most disaster-prone region in the world. Climate-related hazards, like storms, floods and drought, have affected more people – six times more people – in the Asia-Pacific than in the rest of the world combined. Unlike most other wealthy states, Australia is a near-neighbor to many less developed countries. Over 420 million people live to our immediate north in maritime Southeast Asia, densely concentrated in low-lying coastal areas and on island nations that are among the most vulnerable in the world to climate change (Eckstein et al. 2019).

As the climate continues to warm, these countries will come under enormous pressure from increasing and intensifying disasters and their cascading impacts on society. Large numbers of people will be displaced, political instability will increase and conflict will become more likely (Glasser 2019).

Figure 15: Australia is surrounded by some of the most disaster-prone countries on earth.

BOX 2: CONTINUED

The risks of food insecurity are of particular concern. The reefs of the 'Coral Triangle' of Indonesia, Malaysia, Timor-Leste, the Philippines, Papua New Guinea and Solomon Islands create the 'nursery' for roughly 10% of the global fish supply and an important source of food for more than 130 million people in the region (Cruz-Trinidad 2014). The Intergovernmental Panel on Climate Change has concluded that 70–90% of coral reefs will be lost at just 1.5°C of warming – a level we may reach in less than a decade (Xu et al. 2019) – and that 2°C of warming will result in the total loss of coral reefs from all of the world's tropical and subtropical regions.

This loss would occur simultaneously with other profound climate impacts that further undermine regional food security. For example, scientists have determined that warming oceans are already driving fish species towards the poles in search of cooler waters. At 2°C of warming, this will result in a loss of up to 60% from the fish catch in the tropics (Holmyard 2014).

Increasing temperatures, sea-level rise and extreme weather, such as droughts, floods and storms, will further undermine food security. Crop yields will be severely affected as temperatures rise, rainfall patterns change, the reach of crop pest increases and the range of the predators that keep the pests in check shifts (Miller 2017).

The flooding from sea-level rise and storm surge will disrupt livelihoods and cause large-scale population displacement. In Indonesia alone, 50 million *additional* people will be affected at 1.5°C of warming (IPCC 2018).

More frequent droughts and fires will compound the problem. The fires affecting Indonesia in 2015 were indicative of the potential scale of the impacts. Those fires, which burned 2.6 million hectares (an area four and half times the size of Bali), were fed by drought and exacerbated by an El Niño (World Bank 2016). Tens of millions of Indonesians suffered health effects and economic disruptions. The cost to the Indonesian economy was over US$16 billion.

Even without incorporating a wide range of these likely, simultaneous hazards, scientists have determined that by 2040 at 2°C of warming, Southeast Asia's per capita crop production will have declined by one-third (IPCC 2018). Similar impacts occurring outside the region will significantly reduce the options available to countries to offset the domestic effects, such as importing additional food, as Indonesia did on an unprecedented scale during its severe drought in 1998.

As the record-setting disasters of the past few years suggest, the pace of climate impacts is accelerating. At the same time, the window of opportunity to keep the warming below the critical 2-degree threshold is rapidly closing. Australia must play a leading role in advocating for urgent and ambitious climate action, not just because we're especially vulnerable to the hazards that climate change is amplifying, but also for humanitarian and national security reasons. Climate impacts that affect our regional neighbors' food security, economic interests and political stability will rapidly undermine our own security.

5. By the numbers

5.1 2019-20

At 1.52°C above the long-term average, 2019 was Australia's hottest year on record, breaking the previous record, set in 2013, by a staggering margin of 0.21°C (BoM 2020). 2019 was also Australia's driest year on record. The record heat and record low rainfall set the stage for the Black Summer of 2019-20. Globally, 2019 was the second warmest year on record at the time (NOAA 2020a), and was immediately surpassed by 2020.

Figure 16: Record heat and dryness set the stage for Australia's Black Summer.

Globally, 2020 was the second warmest year on record, just 0.02°C behind the record set in 2016 (NOAA 2021a). Remarkably, 2020 registered as the hottest year despite being a La Niña year. Under normal circumstances, we would expect La Niña years to be slightly cooler than average due to cool surface waters in the tropical Pacific Ocean. 2020, despite being a La Niña year, was warmer than any year other than 2016, including those that were boosted by an El Niño event. Also in 2020, the world's oceans reached their warmest level in recorded history (Cheng et al. 2021).

Globally, disasters caused economic losses of US$210 billion (AU$272 billion) in 2020 (Munich Re 2021). As in previous years, the vast majority of these losses were from weather-related disasters including floods, wildfires and storms. The US suffered a record year of climate-fuelled disasters, with US$95 billion (AUD$123 billion) in recorded losses, including a record 22 major disasters (defined as causing at least US$1 billion in damages) (NOAA 2021b). China's devastating floods, beginning in June, were the single most costly disaster of 2020, with losses estimated at US$32 billion (AU$42 billion) (Kramer and Ware 2020).

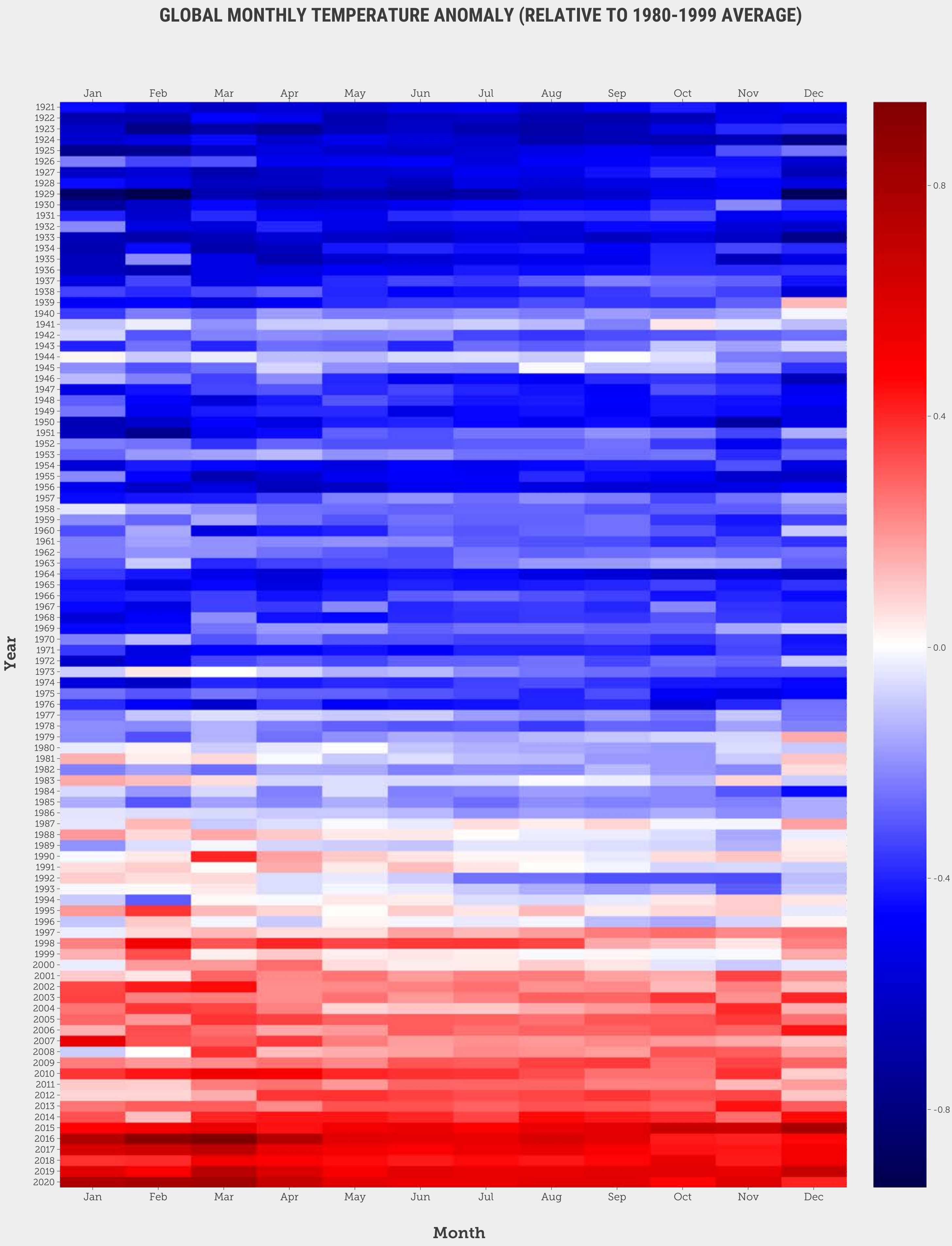
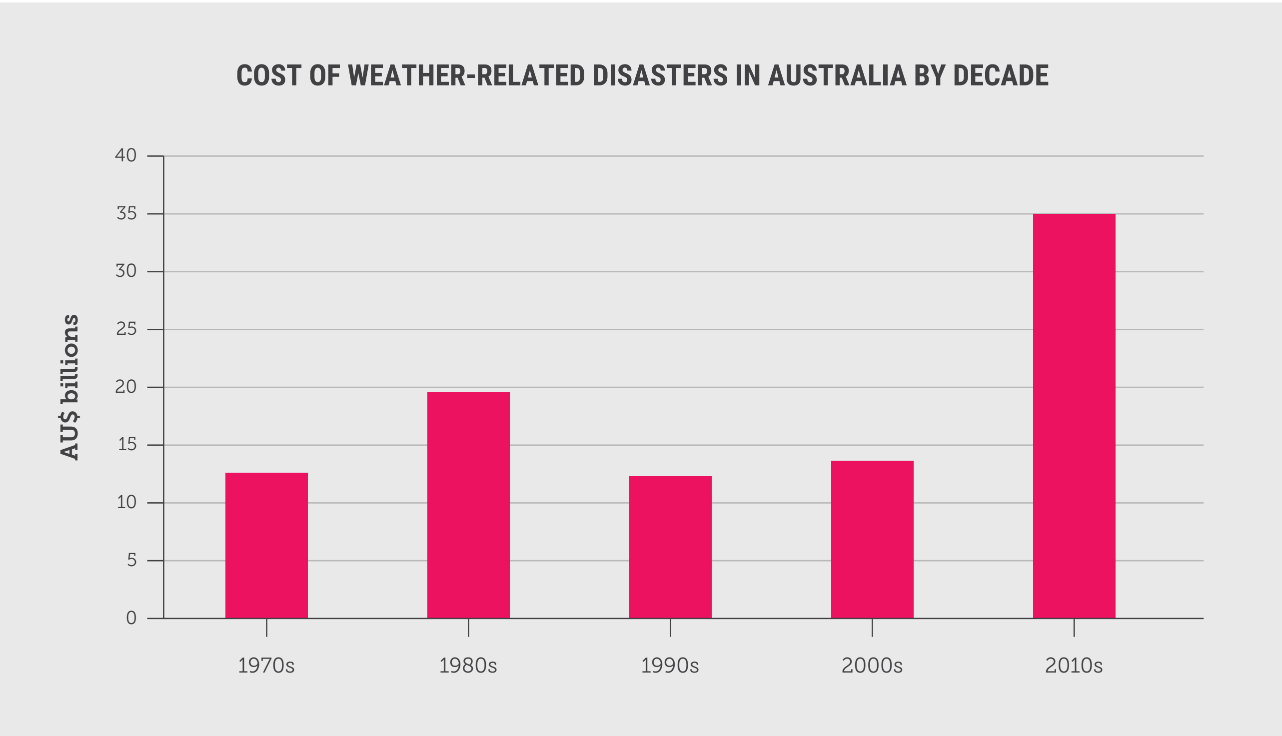


Figure 17: Global monthly temperature anomaly (relative to 1980-1999 average). **Source:** NOAA 2020b.

5.2 Long-term trends

An analysis of data from the International Disaster Database maintained by the Centre for Research on the Epidemiology of Disasters (EM-DAT) shows a significant rise in the cost of weather-related disasters in Australia. After adjusting for inflation, the costs have more than doubled since the 1970s (Figure 18). Recent modelling suggests that the economic cost of climate change to Australia will rise much further over the coming decades. Annual damages from extreme weather, along with sea-level rise and other impacts of climate change upon Australia, could exceed $100 billion by 2038 (Kompas 2020).

Figure 18: Cost of weather-related disasters in Australia by decade.[6] Based on data from EM-DAT, the International Disaster Database: https://www.emdat.be/



6 This analysis covers all weather-related events in the EM-DAT database for Australia between 1970 and 2019, in accordance with the following classifications: storm (convective storm, extra-tropical storm, tropical cyclone), flood (coastal flood, flash flood, riverine flood), wildfire, drought, extreme temperature (cold wave, heat wave, severe winter conditions) between 1970 and 2019. Costs were first converted from US$ to AU$ using the exchange rate of the day, and then adjusted for inflation so as to be equivalent to AU$ in 2019. Historical exchange rates and data on inflation was accessed from the Reserve Bank of Australia.

EM-DAT: https://www.emdat.be/

Exchange rate data: https://www.rba.gov.au/statistics/historical-data.html

Inflation data: https://www.rba.gov.au/calculator/annualDecimal.html

The rise in cost is likely due to both climate and non-climate-related factors. The latter include growth in population and the number of people living in exposed areas.

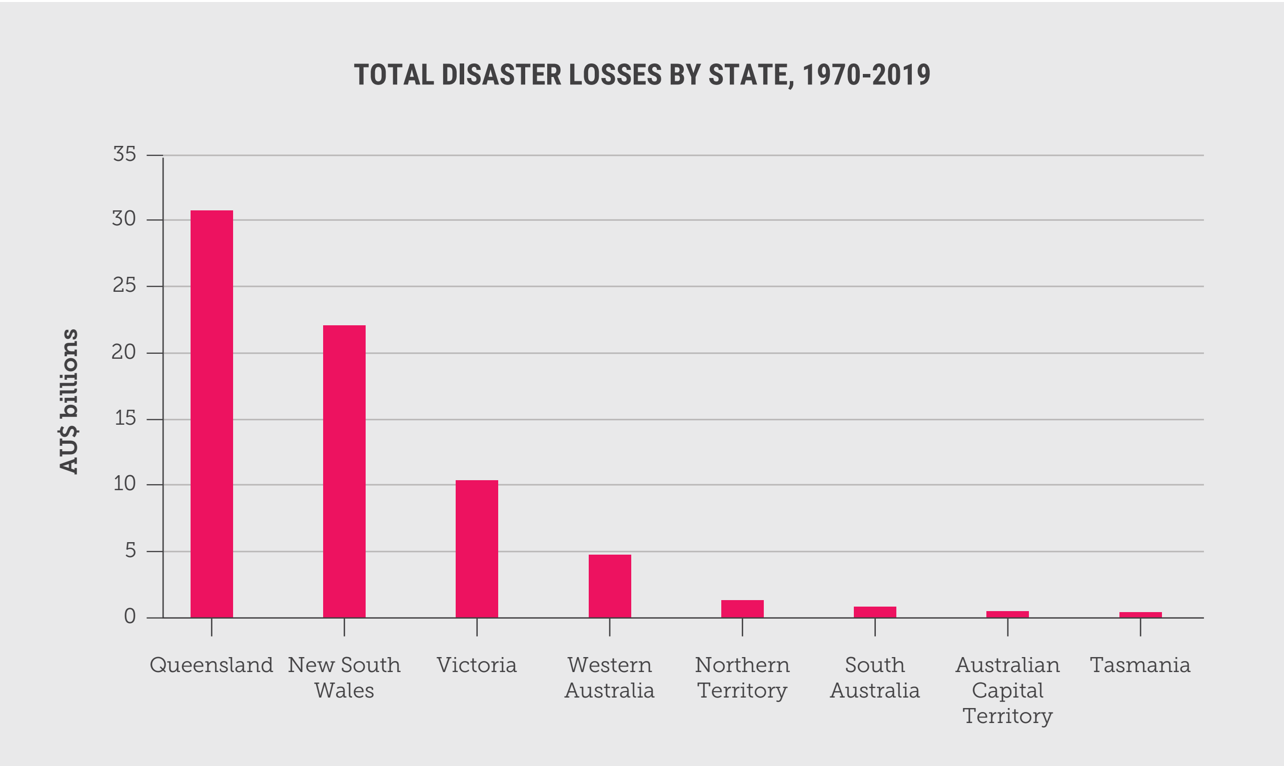
Queensland carries the greatest weight of disaster costs among Australian states and territories (Figure 19).

Queensland's total losses from extreme weather disasters since the 1970s were around three times those of Victoria, and about 50% greater than NSW. On a per person basis, Queensland's losses were more than twice the national average. Heavy damage from floods, drought, fires and storms meant New South Wales suffered greater economic damage from extreme weather disasters than any states or territory except for Queensland, which also faces heavy damage from tropical cyclones. On a per person basis, losses in New South Wales were around double those in Victoria, and quadruple those in Tasmania.

Once these cumulative costs in Figure 19 are adjusted for population size,[8] the states/territories can be ranked as follows in terms of their vulnerability to economic damages from extreme weather:

1st Queensland
2nd Northern Territory
3rd New South Wales
4th Western Australia
5th Victoria
6th Australian Capital Territory
7th Tasmania
8th South Australia

Figure 19: Cumulative economic damages by state/territory (1970-2019).[7] Based on data from EM-DAT, the International Disaster Database: https://www.emdat.be/



7 This analysis covers all weather-related events in the EM-DAT database for Australia between 1970 and 2019, in accordance with the following classifications: storm (convective storm, extra-tropical storm, tropical cyclone), flood (coastal flood, flash flood, riverine flood), wildfire, drought, extreme temperature (cold wave, heat wave, severe winter conditions) between 1970 and 2019. The costs are as recorded at the time of the event, and have been converted from US$ to AU$ using today's rate.

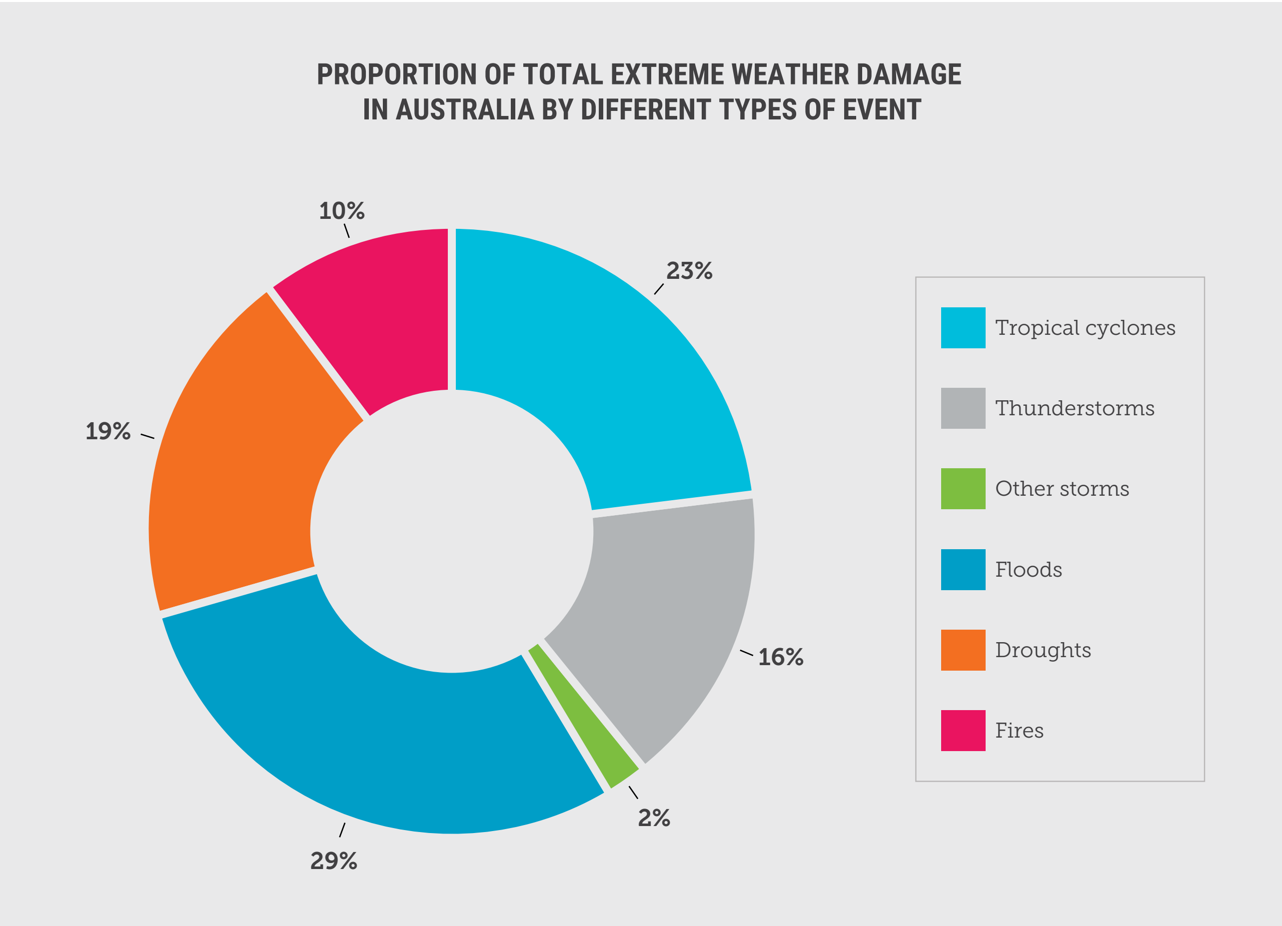
EM-DAT: https://www.emdat.be/

8 Population data: https://www.abs.gov.au/statistics/people/population/national-state-and-territory-population/latest-release

Floods made up the greatest proportion of economic damages from extreme weather in Australia over the last decade, followed by tropical cyclones and droughts (Figure 20).

Globally, the 2010s was by far the costliest decade on record for extreme weather catastrophes (Aon 2020). Australia has faced particularly heavy costs relative to many other countries. On a per capita basis, economic damages from extreme weather disasters in Australia were around seven times the global average. While slightly lower than those for the US, they were far greater than for other developed countries including New Zealand, Canada, the UK and the average across European Union countries.[10]

Figure 20: Proportion of total extreme weather damage in Australia (2010-2019) by different type of event.[9] Based on data from EM-DAT, the International Disaster Database: http://www.emdat.be/

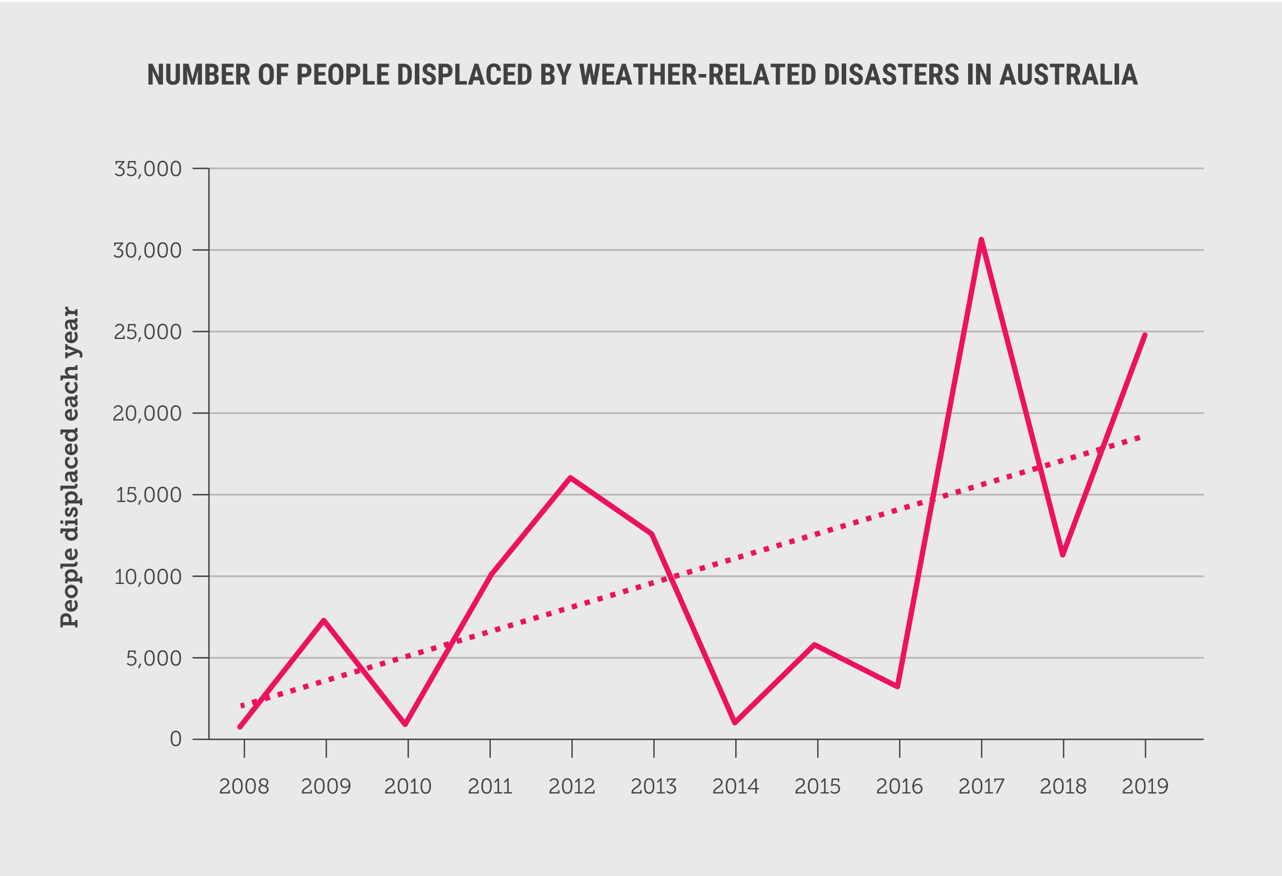


9 'Floods' includes coastal floods, flash floods and riverine floods.

Economic costs give us only part of the picture when it comes to the toll of weather-related disasters, which also result in mental trauma, damage to ecosystems, loss of wildlife and many other forms of loss and damage. Similarly, economic costs, at least when measured in absolute terms rather than as a proportion of GDP,[11] do not capture the disproportionate impact of weather-related disasters upon lower-income countries (UNDRR 2020).

The number of people being forced from their land and home by weather-related disasters provides us with another indicator, one that may go a little further towards capturing the true human cost. Data from the Internal Displacement Monitoring Centre (IDMC) on forced displacement from extreme weather disasters in Australia shows an upward trajectory since records began in 2008 (Figure 21).

Figure 21: Number of people displaced by extreme weather disasters each year in Australia. Based on data from the Internal Displacement Monitoring Centre (IDMC): https://www.internal-displacement.org/



10 Based on data from EM-DAT, the International Disaster Database: http://www.emdat.be/
Population data: https://data.worldbank.org/indicator/SP.POP.TOTL

11 Notably, when measured as a proportion of GDP, economic damages among Pacific Island Countries are much higher than in Australia, even though Australia's losses per capita are greater than those in the Pacific. The latter is in part a function of the greater wealth and greater monetary value of property, infrastructure and other assets in Australia.

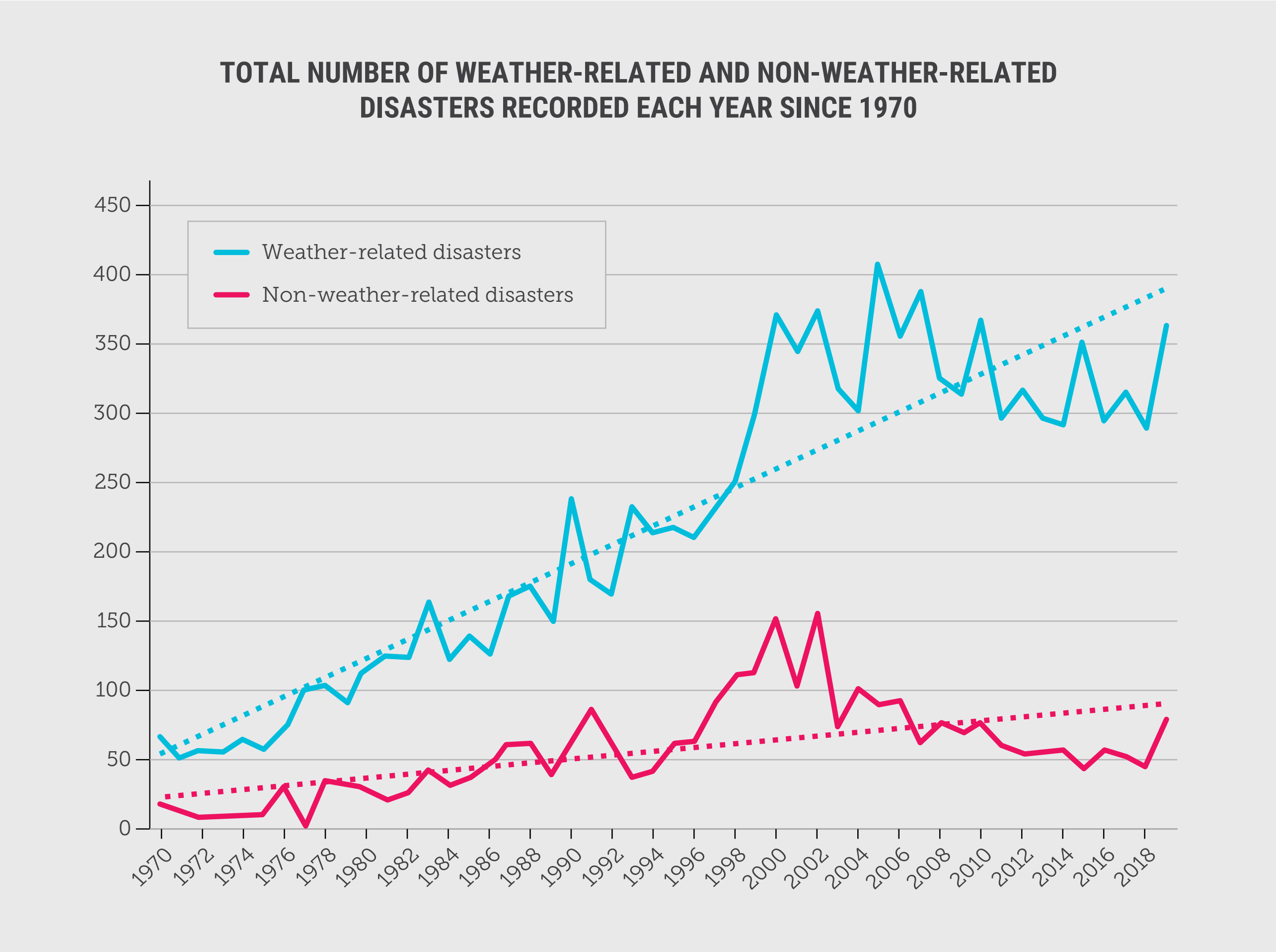
Australians are five times more likely to be displaced by a climate-fuelled disaster than Europeans.

IDMC data also enables us to assess the relative vulnerability of Australians to forced displacement compared to citizens of other countries. Our analysis shows that in Australia, the risk of being displaced by a climate-fuelled disaster is, on average, around five times greater than for people living in Europe.[12] However, for a person living in the Pacific, the risk of displacement is on average more than 100 times greater than for a person living in Europe. The latter highlights the disproportionate impact of climate change on Australia's Pacific neighbours, who despite contributing almost nothing to the causes of climate change are facing some of the most severe consequences.

Overall, data from the Centre for Research on the Epidemiology of Disasters (EM-DAT) show a large increase in the number of extreme weather disasters worldwide since the 1970s (Figure 22). A possible explanation could be that we have simply become more thorough in our recording of events than in the past. However, were that the case, we would expect to see a similar rise in the number of non-weather-related disasters such as earthquakes to the number of storms, floods and other weather-related disasters. Notably, the data show a much steeper rise in the number of weather-related disasters than non-weather-related disasters, strongly suggesting that the rise in recorded weather-related-disasters reflects a genuine trend.

12 We used the full IDMC dataset for weather-related disasters to determine the relative risk of displacement in different countries by calculating the percentage of each country's population that faced displacement, on average, across each year for which data is available.

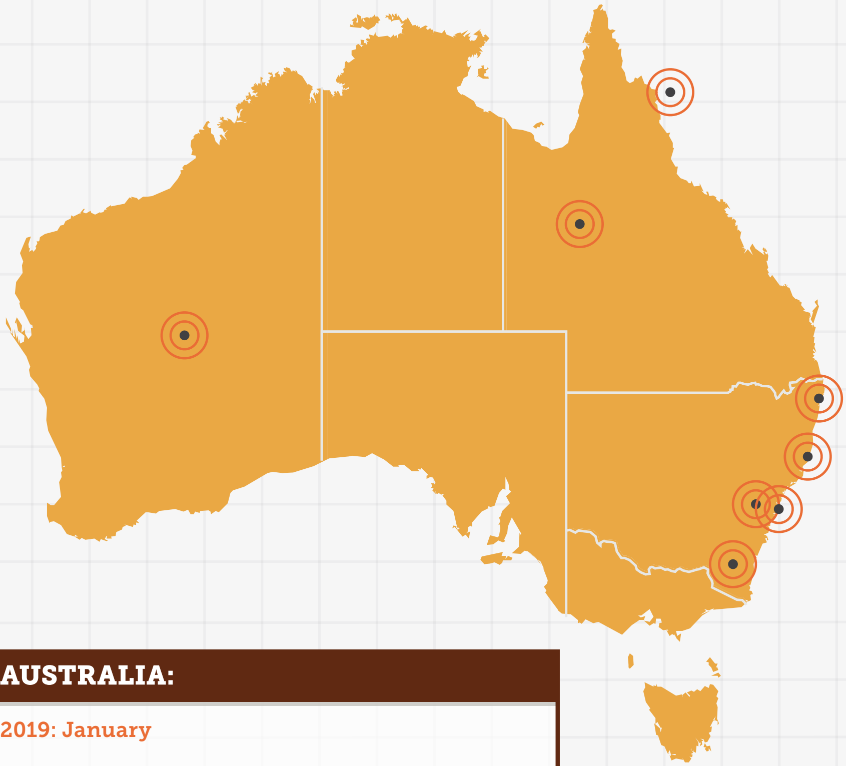
Figure 22: Total number of weather-related and non-weather-related disasters recorded each year since 1970. Based on data from EM-DAT, the International Disaster Database: https://www.emdat.be/



6. Major events in Australia and around the world

Figure 23: Flooding in Townsville,2019.

2019/20 MAJOR EVENTS ACROSS AUSTRALIA



AUSTRALIA:

2019: January

> Extreme heatwave makes the 2018-19 summer the hottest on record at the time.

2019: November to December

> The unprecedented Black Summer fires burn through millions of hectares and kill or displace around 3 billion animals.

2019: December

> Driest and by far the warmest December recorded in Australia.

2020: September to November

> Hottest spring and hottest November on record, despite La Niña event. Deemed virtually impossible in absence of climate change.

QUEENSLAND:

2019: February

> Over half a million cattle are killed by floods in northwest Queensland.

2020: March

> The third mass bleaching event in five years is reported on the Great Barrier Reef. See CASE STUDY: Coral mortality.

NEW SOUTH WALES:

2020: January

> 4 Jan: Penrith was the hottest place on earth at 48.9˚C.

2020: February

> 7-10 Feb: Sydney receives more rain in four days than over the entire six months prior, dousing fires and filling dams.

2020: July

> In one of many severe coastal erosion events this year, huge swells and high tides damaged beaches and property along Sydney's northern beaches and the NSW Central Coast.

2020: December

> Heavy rain, high winds and high tides wreak havoc across NSW northern rivers and southern Queensland, including catastrophic beach erosion at Byron Bay.

WESTERN AUSTRALIA:

2019:

> Warmest year and second driest year on record.

2020:

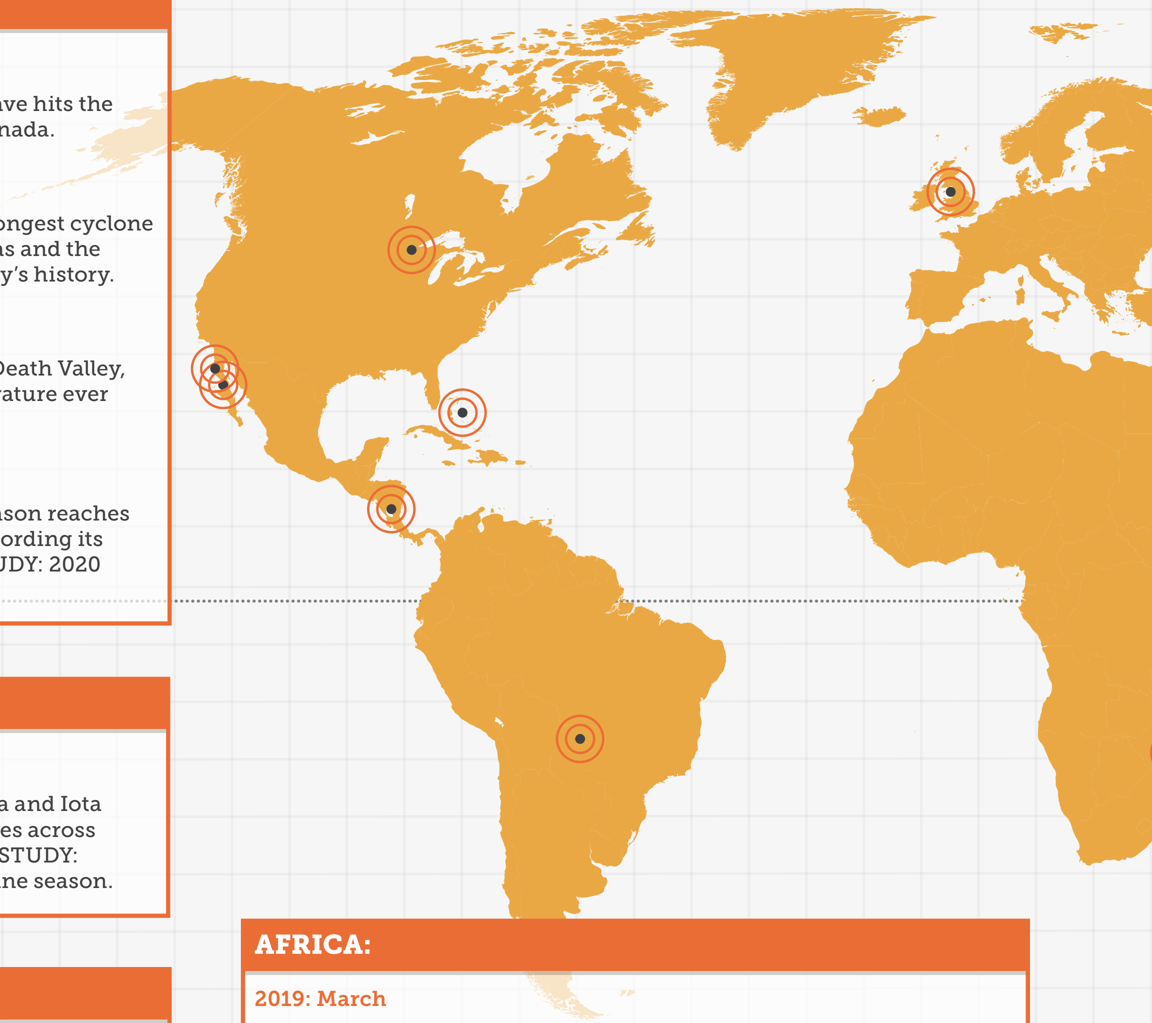
> Second warmest year on record.

CANBERRA:

2020: January

> 20 Jan: Giant hailstones batter Canberra, damaging cars and houses.

2019/20 MAJOR EVENTS AROUND THE WORLD



NORTH AMERICA:

2019: January to February

> A severe and deadly cold wave hits the US Midwest and eastern Canada.

2019: August

> Hurricane Dorian is the strongest cyclone on record to hit the Bahamas and the worst disaster in the country's history.

2020: August

> 16 Aug: 54.4˚C recorded in Death Valley, possibly the highest temperature ever reliably recorded on Earth.

2020: October

> Record-breaking US fire season reaches its peak, with California recording its first 'gigafire'. See CASE STUDY: 2020 US West Coast fires.

CENTRAL AMERICA:

2020: November

> Back-to-back hurricanes Eta and Iota devastate many communities across Central America. See CASE STUDY: 2020 North Atlantic hurricane season.

SOUTH AMERICA:

2020: August to September

> Record fires burn over a quarter of the Pantanal, the world's largest tropical wetlands.

ANTARCTICA:

2020: February

> Highest temperature ever recorded on Antarctica – 18.4°C.

AFRICA:

2019: March

> Cyclone Idai, one of the deadliest cyclones on record in the Southern Hemisphere, causes catastrophic damage in Mozambique, Zimbabwe and Malawi.

2019: April

> Cyclone Kenneth, the strongest recorded cyclone to make landfall in Mozambique, hits just a month after Cyclone Idai.

2020: March to May

> Intense rainfall causes widespread flooding and landslides in East Africa. Hundreds are killed and hundreds of thousands are affected. Kenya and Somalia are among the worst affected countries.

2020: November

> Cyclone Gati, the strongest landfalling cyclone recorded in Somalia, brings over a year's worth of rain in two days.

UK:

2020: October

> 3 Oct: UK records wettest day since records began in 1891.

SIBERIA:

2020: January to June

> An intense, persistent and widespread heat wave across Siberia broke temperature records, fuelled large fires, and thawed permafrost. See CASE STUDY: 2020 Siberian heatwave.

NORTHERN HEMISPHERE:

2020: July to August

> Hottest northern hemisphere summer on record.

2020: July

> Lowest Arctic sea ice extent for July since beginning of satellite observations in 1979.

ASIA:

2019: June to October

> Monsoon floods cause 1,750 fatalities in India – 2019's most deadly extreme weather event.

2019: October

> Typhoon Hagibis is the strongest and deadliest cyclone to hit Japan since Typhoon Tip in 1979.

2020: January

> Record floods in Indonesia kill at least 19 people. Highest daily rainfall in Jakarta since records began.

2020: May

> Cyclone Amphan rapidly intensifies into a category five storm before tearing into eastern India and Bangladesh. It becomes the costliest cyclone on record for the north Indian Ocean, with losses in India of around US$14 billion.

2020: June

> Worst flooding along the Yangtze and its tributaries for decades affect more than 60 million people and cause estimated losses of US$32 billion.

2020: July

> Flooding in India (Assam) and Nepal displaces millions. A third of Bangladesh is underwater. See CASE STUDY: 2020 Asian Monsoon floods.

2020: November

> The Philippines hit by Typhoon Goni, the strongest landfalling tropical cyclone on record.

GLOBALLY:

2019: July

> Hottest month ever recorded globally.

2020: January

> Hottest January on record globally.

2020: September

> Hottest September on record globally.

2020: November

> Hottest November on record globally.

PACIFIC:

2020: April

> Cyclone Harold, the strongest cyclone to hit Vanuatu since record-breaking Cyclone Pam in 2015, causes widespread damage in Vanuatu, Solomon Islands, Fiji and Tonga.

2020: December

> Cyclone Yasa, exceptionally strong for this early in the season, causes heavy damage on Fiji's northern island of Vanua Levu.

7. We must act with more urgency

Politically, 2021 will be the most important year for international action on climate change since the Paris Agreement was adopted in 2015, and perhaps ever. The intervening years have revealed the tremendous - and rapidly escalating - costs of the climate crisis and the perilous gap between the action that countries have committed to taking and the pace of action required to avert catastrophe. Nowhere is this starker than in Australia.

Countries have until November 2021 – before the next crucial round of international climate negotiations at COP26 in Glasgow – to announce new commitments that will close the gap between current collective efforts and what the science demands. Decisions made in the lead up to Glasgow, including how governments choose to spend trillions of dollars in economic renewal, will profoundly affect the security, wellbeing and prosperity of generations to come – and reverberate beyond human timescales.

Despite, or perhaps because of, the disruption of COVID-19, there has been an encouraging upswing in the world's response to the climate crisis in 2020. Less than a year ago, only around a fifth of Australia's two-way trade was with countries committed to net zero emissions by around mid-century. By the end of 2020, that number had shot up to more than 70%, including the three biggest buyers of Australian coal and gas: China, Japan and South Korea. More and more countries have recognized that climate action, and in particular clean energy, is not only essential to our common wellbeing but is also the fast track to economic recovery from COVID-19.

When the US is included, more than 60% of global emissions are covered by a commitment to net zero emissions by around mid-century. More importantly, many of the world's biggest emitters, including the EU, US, UK, China and Japan, have either strengthened their commitments to 2030 or plan to do so.

Figure 24: Australia has enormous potential for renewable energy and clean industries.

Encouraging as these developments have been, they remain insufficient if we are to stay under the long-term temperature limits identified in the *Paris Agreement* and ensure a future in which Australians everywhere can not only survive but thrive. To maintain a fair chance of limiting warming to well below 2°C, we must halve global emissions over the coming decade, and achieve net zero emissions before 2040 (Steffen et al. 2020). While few countries, and almost no major economy, are acting with the urgency that this crisis demands, Australia is a true outlier. We stand alone in refusing to commit to achieving net zero emissions by 2050 or earlier (or 2060 in the case of China), or to strengthening our 2030 emissions reduction target.

Today the Australian government faces pressure from many angles to commit to much stronger climate action – both domestically and internationally.

Australia now faces serious pressure from the US, our number one strategic ally, to do far more to address the climate crisis. Commitments by our big trading partners in Asia to move beyond fossil fuels adds to this international pressure and will soon translate into lost export revenues and jobs unless Australia rapidly shifts towards renewable-generated exports. We also face the very real prospect of carbon tariffs being placed on our exports, beginning with the EU, until we have a carbon price of our own.

Closer to home, Pacific leaders have grown angry and impatient with Australia for recklessly endangering the future of their communities and our region. China's growing presence in the region – and its willingness to go further in taking climate action - should be a cause of concern for us. Even the UK's historical, strategic and cultural ties to Australia have not prevented it from calling out our failures ahead of COP26, which it will host.

Despite the federal government's climate inaction, Australia is still making progress thanks to leadership from the states and territories, local governments and business. The Australian public, 80% of whom were in one way or another directly affected by the Black Summer fires (Biddle et al. 2020), continue to demand that our national government rise to the challenge. Similarly, investors are increasingly using their voice and their dollars to drive change.

Just as the pressure for action has never been greater, nor coming from so many different directions, so too have the opportunities for Australia to flourish in a post-carbon world never been clearer.

Renewable energy is already cheaper than fossil fuels, employs more people – particularly in regional Australia - and can be rapidly expanded (Climate Council and Alpha Beta 2020). Australia has many competitive advantages that are the envy of the world: we are the sunniest and one of the windiest countries and have the space and technical expertise necessary to make use of our renewable resources. Tapping into renewable energy can repower our homes, businesses and transport. It can also become the foundation for new low and zero carbon manufacturing industries, tapping into growing global demand. Furthermore, renewable hydrogen and other emerging technologies provide Australia with an opportunity to build a world-leading renewable export industry, setting up economic prosperity for generations to come. Yet despite our enviable natural advantages, Australia currently risks being left behind.

Not so long ago, it was common to say that we must limit warming to below 2°C below pre-industrial levels to "avoid dangerous climate change". Today, it is clear there is no "safe" level of warming. Already, at 1.1°C of warming, we are witnessing a deadly rise in extreme weather events and damage to critical ecosystems upon which our lives depend. Limiting warming to 1.5°C – as agreed in Paris – would avoid even more severe risks associated with 2°C or more of warming (IPCC 2018). However, decades of inaction have already rendered this virtually impossible. Allowing warming of 2°C and beyond would risk tipping the Earth onto a perilous 'Hothouse' trajectory and a barely survivable future (Steffen et al. 2018; Lenton et al. 2019).

Australia is facing enormous pressure from many quarters, but we also have a massive opportunity to become a post-carbon world powerhouse.

As we enter the decisive and transformative decade for climate action, Australia must do everything it can to help, recognizing our unique natural advantages, our responsibilities as an advanced economy and the vulnerability of our own communities and economy. This begins with targets based on the science, and a comprehensive plan of action that mobilises every section of our society around a shared vision. It means acting today, not tomorrow. It means at least halving our emissions by 2030, and achieving net zero emissions as soon as possible, and by 2040 at latest. It means pivoting from being one of the world's largest exporters of fossil fuels to being a global powerhouse of renewable energy and clean industries.

Failure will be felt in loss of life, catastrophic economic losses, in more people being forced from their homes by extreme weather disasters, in the loss of species and entire ecosystems, and in the undermining of everything we hold dear. In other words, failure is not an option.

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