AIM HIGH, GO FAST: WHY EMISSIONS NEED TO PLUMMET THIS DECADE

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Cover image: 'Trail runners running and training in the hills and mountains of the Alps in Europe, running towards a steep and snowy mountain along a trail in summer' by Andre Gie / Shutterstock.com.

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Key findings

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Climate change is accelerating with deadly consequences. The ecological systems that have sustained human life and societies for generations are being severely damaged by increasing heat and worsening extreme weather events.

› There is no safe level of global warming. Already, at a global average temperature rise of 1.1°C, we're experiencing more powerful storms, destructive marine and land heatwaves, and a new age of megafires.

› Multiple lines of evidence strongly suggest that we can no longer limit warming to 1.5°C without significant overshoot and subsequent drawdown, and that the global average temperature rise will exceed 1.5°C during the 2030s.

› Should temperatures spike above 1.5°C for a significant period of time, critical ecosystems on which we depend (such as the Great Barrier Reef) would be even more severely damaged, or destroyed.

› Every fraction of a degree of avoided warming matters, and will be measured in lives, species and ecosystems saved. We must do everything possible to deeply and rapidly cut our emissions, while also preparing for climate impacts that can no longer be avoided.

› There's little time left to limit global warming below catastrophic temperature rises. Breaching 1.5°C of warming significantly increases the risk of triggering abrupt, dangerous and irreversible changes to the climate system.

2

Our response must match the scale and urgency of this worsening situation. Action to deeply reduce emissions *this decade* will determine whether warming can or cannot be held to well below 2°C.

› While action is increasing in Australia and world-wide, it remains too slow and not enough. Protecting Australians from the worsening effects of climate change requires all governments, businesses, industries and communities to strongly step up their activities to deeply reduce emissions during the 2020s.

› The lion's share of the effort to get to net zero emissions needs to happen *this decade.* Delaying further than we have already would mean that even more rapid and disruptive action to reduce emissions is required later.

› Governments, business and industry are committing increasingly to net zero targets. However, timeframes for these commitments are generally too long. The world achieving net zero by 2050 is at least a decade too late and carries a strong risk of irreversible global climate disruption at levels inconsistent with maintaining well-functioning human societies.

› Australian governments, businesses, industries and communities can and must cut emissions deeply. Given the scale of the global emissions reduction task, and taking into account Australia's very high level of emissions and our huge renewable energy resources, Australia should aim to reduce emissions by 75% below 2005 levels by 2030 and reach net zero emissions by 2035. This is a fair and achievable contribution to the global task and an imperative given our high vulnerability to escalating extreme weather.

3

As momentum for climate action gathers speed around the world, all efforts must now focus on steps that can be taken *this decade.*

- The change in US government has ushered in a new era of international cooperation on climate change. All commitments must be scaled up, and the pace of action must accelerate if we are to avoid the worst climate consequences.
- Australian state and local governments as well as many leading business and community groups are already providing vital leadership in implementing climate solutions.
- Many of Australia's strategic allies and major trading partners (including the US, EU, UK, Canada and China) have strengthened their climate commitments for this decade, or intend to do so. The Australian Federal Government is standing still, and alone.
- Australia, as a major emitter in its own right and a giant of the global fossil fuel economy, has a major role to play in the global effort to stabilise the climate. Bold and decisive climate action ultimately protects us and is in our national interest.

4

Australia has everything it needs to act swiftly and decisively to help avert climate catastrophe, and prosper in a global clean economy.

- Australia has unrivalled potential for renewable energy, new clean industries, and clean jobs. We need to rapidly scale up the energy transition and advance solutions in other sectors including transport and agriculture.
- Climate leadership from states and territories has shown what works, and the benefits that decarbonising our economy can bring, such as regional jobs, cleaner cities and cheaper power. It's time for a concerted national push, and for the Federal Government to work with other tiers of government, along with industry and communities, to rapidly step up this work and deliver much deeper cuts in emissions.
- Despite our natural advantages, we are being left behind in the new, clean economy race. Urgently ramping up our ambition is fundamental both to Australia's economic future, and to ensure our children and grandchildren can not only survive but thrive.
- The change will not always be smooth. There are political, technical and other challenges ahead because action has been delayed. However, the alternative – a decision to not do enough, or to delay – will lead to massive climate disruption. Catastrophic outcomes for humanity cannot be ruled out if we fail to meet the climate challenge *this decade.*

Foreword

As climate scientists, we have observed with mounting concern the continuing emissions and the rise in atmospheric concentrations of carbon dioxide and other greenhouse gases. For decades, we have issued dire warnings about what is at stake and what is required to curb global warming. Yet global temperatures continue to rise, along with damages from extreme weather.

Encouraging global shifts are underway, including the uptake of renewable energy and recent climate commitments from the US, the EU, the UK, and others. This is the beginning of the global action that is required, but it is far from the scale and pace needed to avert far more severe, long-lasting and irreversible changes. Moreover, commitments to reduced net emissions to zero (net zero) must be matched by appropriate actions.

Multiple lines of evidence show that limiting global warming to 1.5°C above the pre-industrial level, without significant overshoot and subsequent drawdown, is now out of reach due to past inaction. The science is telling us that global average temperature rise will likely exceed 1.5°C during the 2030s, and that long-term stabilisation at warming at or below 1.5°C will be extremely challenging. Should temperatures spike above 1.5°C for a significant period of time, the ecosystems on which we depend will be even more severely damaged. Climate-related damages will be widespread and could, in some settings, be an existential threat.

As temperatures rise, so too do the consequences. Australia and many other regions have suffered losses, but there is still so much to be protected and saved. Warming avoided can be measured in lives, species and ecosystems saved. This is why it is vital to strive towards achieving the long-term goals of the *Paris Agreement*.

Getting global emissions down to net zero as quickly as possible is the top priority. Given continuing emissions and the pace at which temperatures are rising, the science shows that globally, to keep temperature rise to well below 2°C without overshooting to higher values, emissions need to be halved by 2030, and there is a need to get to net zero by 2040 at the latest.

This report *"Aim High, Go Fast"* is the Climate Council's science-backed vision for what Australia's best effort could look like. Australia is a nation of currently high emissions but rich renewable energy resources. The country has been ravaged by unprecedented bushfires, droughts, and floods in recent years, and decision makers should not ignore these warnings.

To be sure, the task before us is massive, and the scale and pace of change required will need all-of-society shifts in the way we live, work, and power our economies. There may be some speed-bumps along the way as we develop and adopt solutions, but the right mix of good policy, courage, rapidly emerging new technologies and collaboration can smooth the way.

We as a global community must rise to this challenge, because the deadly consequences of global warming affect every single one of us. Bold, urgent action is the only way to save the people, places, and communities we love.

Australia, as an advanced economy and major emitter, and one with unrivalled potential for renewable energy and other climate solutions, should be a leader not a laggard, and reduce its emissions even faster than the required global average. Every country, perhaps encouraged by Australia, must do its very best to help meet the goals as outlined. Every tonne of emissions avoided matters, and every delay has an escalating cost. We urge you all to take this report seriously and respond accordingly.

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1. Introduction

THE SCIENCE BOTTOM LINE

For at least 30 years, since the publication of the the Intergovernmental Panel on Climate Change (IPCC)'s First Assessment Report in 1990, scientists have issued progressively more urgent calls to tackle the escalating climate crisis.

Despite rapid progress in the availability and affordability of climate solutions, as well as wide-spread engagement of governments, community and business, the scale and pace of action is not meeting the challenge. Meanwhile, around the world, the economic damage of extreme weather is rising, many people are being forced from their land and homes, and critical infrastructure and essential resources are increasingly threatened.

In Australia we have already entered a new era of megafires, more powerful storms and deadly heatwaves. We are witnessing dramatic damage to the ecological systems that sustain human life and our society. From the Black Summer bushfires causing massive air pollution across major cities; to widespread flooding from intensifying rainfall events; to increasing damage to agricultural landscapes from worsening droughts and fires; and to the long-term decline in rainfall across the population centres of the southwest and southeast of Australia – the climate change crisis is now all around us and is accelerating.

Strong, multiple lines of evidence indicate that we will soon exceed 1.5°C of warming above pre-industrial levels. There is no 'safe' level of global warming, but warming of 1.5°C has long been considered a limit we should aim for to minimise the risk of far more severe, long-lasting and irreversible changes.

The science is absolutely clear: too little action, too slowly has led us to this climate crisis.

We now face a more dangerous future, with further risks and damages locked in. In addition, overshooting 1.5°C of warming[1] rapidly increases the risk of triggering abrupt changes – such as the release of vast amounts of greenhouse gases from thawing permafrost – that would greatly accelerate warming and tip our planet towards much harsher, potentially irreversible conditions.

We have reached the endgame and if we are to limit further disruption then we must dramatically step up the scale and pace of action. Inaction or delay in the face

Climate change is already dramatically damaging the ecological systems that sustain human life and our society.

1 The term 'overshoot' refers to a period during which the global average temperature rise exceeds the level of the long-term temperature goal. The long-term temperature goal may still theoretically be achieved through a process of 'drawdown', through which large quantities of greenhouse gases are removed from the atmosphere. These concepts are explored further in Chapter 3.

of so much evidence is in fact an active commitment to massive global climate disruption and damage. All governments, businesses and sectors have a critical role to play.

If we're to protect people, our communities and the ecosystems we depend upon for our survival, then all greenhouse gas emissions need to be reduced rapidly and deeply – cut by more than half globally over the coming decade, with the world reaching net zero by 2040 at latest.

MATCHING THE PACE AND SCALE OF THE CLIMATE CRISIS WITH SOLUTIONS

There is encouraging progress in many parts of the world. Almost all of Australia's strategic allies and major trading partners have a commitment to net zero emissions by mid-century, and, most importantly, many have ramped up their commitments for the coming decade. The Biden-Harris administration has hit the ground running, determined to significantly step up climate action on US soil and to bring the rest of the world along.

Figure 1: Sydney and other major cities were shrouded in bushfire smoke during the Black Summer bushfires (photo taken 10 December 2019).

In order to protect people, communities and ecosystems from massive climate disruption, all greenhouse gas emissions need to plummet over the coming decade.

Australia's national approach has been out of step with global action for many years, and has been regularly criticised at home and abroad. While there has been a vacuum of leadership at the federal level, state and local governments, as well as business, industry and the community, have been stepping up. All states and territories now have net zero targets and have been strengthening commitments to renewable energy.

However, these efforts still fall far short of the pace and scale of action required. The latest assessment of combined global commitments shows barely a dent in total global emissions before 2030 (UNFCCC 2021). Almost all countries, including Australia, need to immediately escalate their efforts, and make far deeper emission reductions before the end of this decade.

In summary, governments, business and industry are committing increasingly to net zero targets. While this is very welcome, timeframes for these commitments are generally too long. The world achieving net zero by 2050 is at least a decade too late and carries a strong risk of irreversible global climate disruption at levels inconsistent with maintaining well-functioning human societies. Rather than the focus being on long-term goals, the most important action is to set emissions on a plummeting downward trajectory during the 2020s.

AUSTRALIA'S NATURAL ADVANTAGE

Australia is primed to meet this challenge. Leadership from states and territories has shown us the way. Technological advancements, plummeting costs, and the unrivalled potential of our sun-drenched continent to generate renewable energy mean we have everything we need to drive far stronger action at home, and to support other countries to do the same.

Embracing our natural advantages in clean energy, zero-carbon manufacturing and other climate solutions will ensure jobs and prosperity for Australians now and for generations to come. It will improve our health, and help protect our natural heritage. Bold and transformative action this decade is not only fundamental to protecting all of us, but can also secure Australia's economic prosperity.

Achieving net zero emissions by 2050 globally would be at least a decade too late.

Given these advantages and opportunities, along with our very high emissions and historical contribution to climate change, Australia can and should cut its emissions at an even faster rate than the required global average. Calculations described in this report (Chapter 4) suggest that to make a fair contribution to the required global effort, Australia should achieve net zero emissions by 2035, and reduce emissions by 75% below 2005 levels by 2030. We should aim high, and we should move fast in order to maximise the benefits and minimise the risks.

We can also use our influence internationally, through climate diplomacy, development assistance, and clean energy exports, to catalyse and support action beyond our shores.

This is not to say that the transition will be easy. The window for concerted action is now so narrow that the effort required must be far faster and stronger than it would have been a decade ago. There will inevitably be hard decisions and disruption in the transition. There are only two alternatives: 1) continuing to do too little, too slowly and therefore choosing to condemn ourselves to massive, irreversible climate damage; or 2) accelerating the major industrial transformation that is already underway and experiencing some disruptions in this transformation. The choice is stark and requires us to think not only of our present but also of our future.

Figure 2: A huge solar farm between Toowoomba and Dalby in central Queensland, Australia. Australia is one of the sunniest countries on Earth and has unrivalled potential to generate renewable energy.

THE ROAD AHEAD

There is no safe level of global warming. Every tenth of a degree of avoided warming matters. This will be measured in lives, species and ecosystems saved, and catastrophic events avoided.

It is still possible to limit the long-term temperature rise to well below 2°C. Beyond that lies extreme danger. However, the only way to achieve this is with a collective push for immediate, strong and sustained climate action.

As the world counts down to a crucial round of international climate negotiations in November 2021 (COP26 in Glasgow), it's clear that the decisions and commitments made this year will reverberate for generations and profoundly affect the wellbeing and prospects of current and future Australians. It's time for Australia to think beyond doing "our bit" and, instead, start doing our absolute best.

ABOUT THIS REPORT

This report lays out the latest physical science of climate change and what it means for all countries, but especially Australia, during this crucial year for advancing international cooperation. It also examines the commitments we must make this year in the lead up to the next UN climate talks (COP26), the scale of action required from Australia this decade, and the opportunities this will unleash.

Chapter 2 explores the costs of past inaction and the urgent need to ramp up our response by setting out multiple lines of evidence for why the global average temperature will soon exceed 1.5°C above pre-industrial levels.

Chapter 3 outlines the things we can and must fight to protect, by exploring the difference between 1.5°C and 2°C of warming. It explains how every tenth of a degree matters, and why every gigatonne of carbon kept in the ground will be measured in lives, livelihoods, species, and ecosystems saved.

Chapter 4 outlines the magnitude of the global challenge and the Australian contribution needed to limit warming to well below 2°C: a goal that remains feasible, but can only be met by a rapid, sustained, long-term downward trend in emissions that starts immediately.

To further explore the urgent need for far stronger action this decade, Chapter 5 looks at the extreme risks of the current climate trajectory, including the growing possibility of triggering 'tipping points' in the Earth System.[2] Drawing on recent work from the Australian Academy of Science, this chapter outlines the confronting reality of what Australia could be like if the world warms by 3°C.

Lastly, Chapter 6 reminds us of Australia's many advantages and unrivalled opportunities in responding to this crisis. Just as no developed country has more to lose than Australia from accelerating climate change, no other country is better placed to prosper in a global clean economy. Every dollar invested in climate solutions avoids further losses, and sets us up to not only survive but thrive. We cannot afford to lag behind.

We know what works. Communities all over the world are already benefiting from stronger climate action. It's time for all of us to step up to the challenge before us, and go as hard as we possibly can.

2 The term Earth System refers to the Earth's many interacting physical, chemical and biological processes among the land, ocean, atmosphere, cryosphere (ice) and lithosphere (rock). It also includes humans, in all our activities and technologies.

We are grateful for insightful feedback received from scientific peer reviewers (Australian and international climate scientists) as well as during extensive briefings and community consultations. Thanks also to Councillors and Climate Council staff for their feedback and assistance in the preparation of this report.

The Climate Council acknowledges the Traditional Custodians of the lands on which we live, meet and work. We wish to pay our respects to Elders past, present and emerging and recognise the continuous connection of Aboriginal and Torres Strait Islander people to Country.

BOX 1: THE PARIS AGREEMENT LONG-TERM TEMPERATURE GOAL

The precise text of the *Paris Agreement* long-term temperature goal (Article 2.1b of the *Paris Agreement*) reads as follows:

> *"Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change."*

This goal replaced an earlier version that referred to holding the increase in global average temperature 'below 2°C', because it was clear that warming of 2°C was too dangerous.

Years of sustained and skilful advocacy by vulnerable countries, in particular Pacific Island Countries, ensured that a stronger temperature goal was placed at the heart of the *Paris Agreement*. This was a triumph for those on the frontlines of the climate crisis. The ensuing Special Report on Global Warming of 1.5°C from the Intergovernmental Panel on Climate Change unequivocally outlined the dangers of 2°C warming relative to 1.5°C; vindicating the push for a stronger temperature goal.

The formulation that countries used to agree upon the long-term temperature goal within the *Paris Agreement* was complex and ambiguous. This report does not explore the detail or interpretations of the *Paris Agreement* itself, but rather focuses on the latest science regarding the current trajectory of the climate system; the impacts and risks already occurring as well as those that lie ahead; and the urgent, strong actions required to hold the global average temperature rise to well below 2°C.

It is vital that we strive as hard as we possibly can towards achieving the goals of the *Paris Agreement*.

2. Why we will soon exceed 1.5°C of global warming

When countries are locked in discussions around emissions targets, and politicians are debating the detail of policies, it is easy to lose sight of what is at stake for all of us. The urgency of the situation cannot be overstated: how we act today will determine how liveable – or unliveable – our world will be.

Several lines of evidence contribute to the argument that we cannot limit the rise in global average surface temperature to 1.5°C above the pre-industrial level, taken as the 1850-1900 average, without significant overshoot and subsequent drawdown. These lines of evidence include: the observed, projected and committed temperature rise; updated estimates of climate sensitivity; insights from past changes in the climate; and analysis of the remaining global carbon budget.

Evidence suggests we cannot limit the rise in global average temperature to 1.5°C above the pre-industrial level without significant overshoot and drawdown.

2.1 Observed and projected trajectory of the climate system

The global mean surface temperature (or 'global temperature' for short) is often used as the key indicator for climate change. Global temperature is now 1.1°C above the pre-industrial level, leaving only 0.4°C of further rise before 1.5°C is breached. More importantly, the rate at which the climate system is warming is itself increasing. This is important because the rate of temperature rise must first be slowed before a multi-decade period of stability can be achieved.

Two key indicators clearly show that rate of climate change is increasing. The first is global temperature. Averaged over the 2016-2020 period, global temperature was about 0.24°C higher than the average of the previous 5-year period (2011-2015) (Canadell and Jackson 2020, based on five global mean temperature data sets synthesised by the UK Met Office). If this rate of increase of 0.24°C is maintained for the next two 5-year periods (that is, no further acceleration occurs), then by 2030 the temperature increase would have reached nearly 1.6°C. If the rate of historical warming over the past 30 years – which is lower than the rate over the past 5-year period and thus reduces the effect of the recent acceleration in temperature rise – continues into the future, then 1.5°C would be overtaken by around 2037 (CarbonBrief 2020).

An analysis of changes in the rate of sea-level rise, the second key indicator, yields a similar conclusion. Averaged globally over the past 27 years, sea level has been rising at 3.2mm/year. Over the past five years, the rate was 4.8mm/year, and for the 5-year period before that the rate was 4.1mm year (Canadell and Jackson 2020, based on data from the European Space Agency and Copernicus Marine Service).

Key indicators show the rate of climate change is increasing. This must be slowed before we can stabilise the climate.

Figure 3: Calving front of an ice shelf in West Antarctica. Melting polar ice sheets are contributing to an acceleration in sea-level rise.

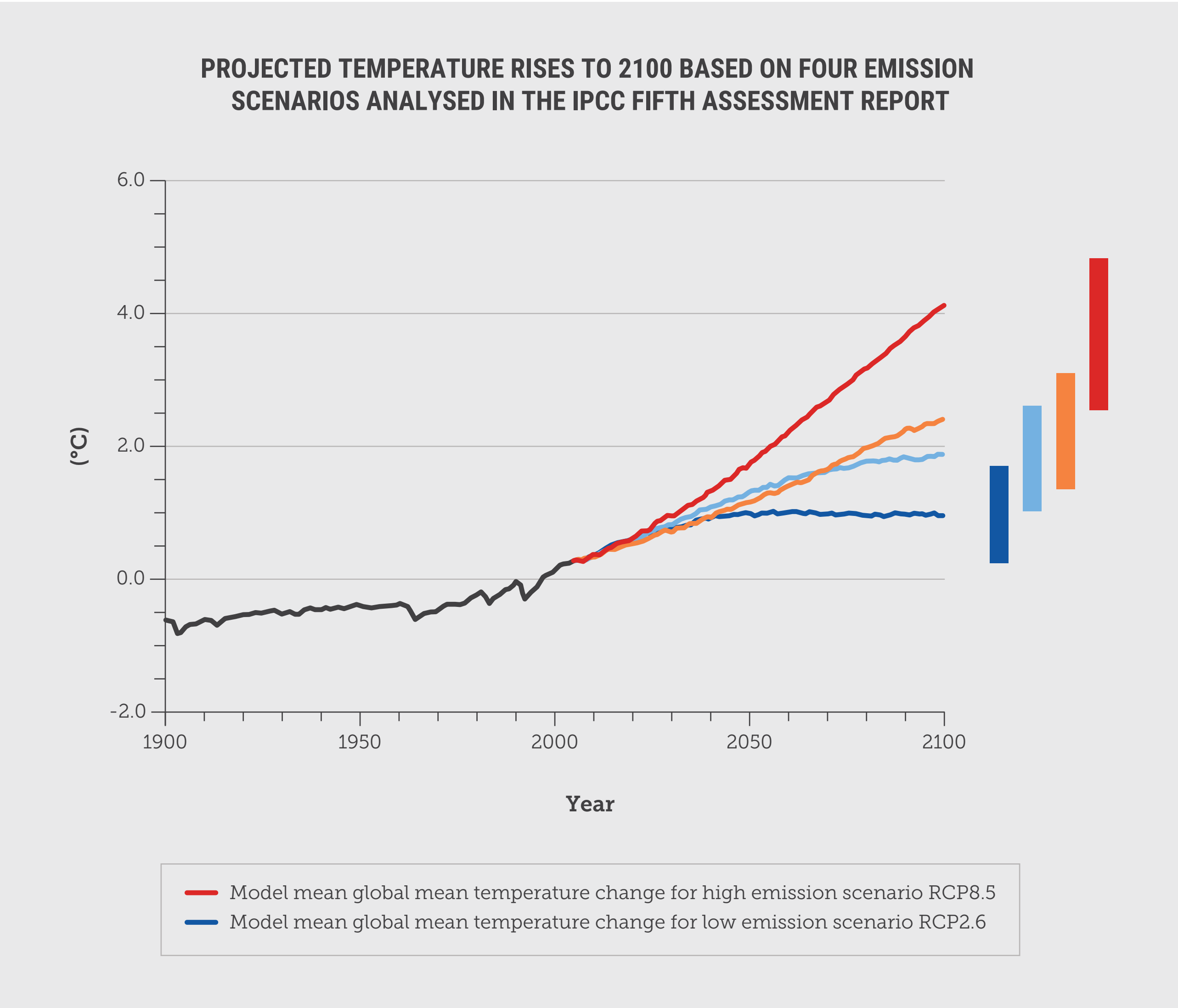
Sea-level rise is primarily caused by two factors: (i) the expansion of the ocean water due to increasing absorption of heat from the warming atmosphere, and (ii) additional water from the melting of polar ice sheets and mountain glaciers. Both of these factors are accelerating. Since 1993, the rate of ocean warming has more than doubled (IPCC 2019). The rate of mass loss from the Antarctic ice sheet over the period 2007-2016 tripled relative to 1997-2006. Over the same period, mass loss from the Greenland ice sheet doubled (IPCC 2019). Given the considerable thermal inertia of the ocean/ice system, the increase in rates of change cannot be halted or reversed in a few years or even a decade or two, and are a clear sign that the warming of the climate system as a whole is accelerating.

In addition to these two key indicators of change in the climate system, an analysis of human emissions of greenhouse gases has, up until now, been tracking most closely (within 1%) to the RCP8.5 emissions scenario.[3] This is the highest of the four emissions scenarios analysed in the IPCC Fifth Assessment Report (AR5) (Schwalm et al. 2020). The Schwalm et al. analysis also projected that RCP8.5 scenario is the most likely for our emissions trajectory out to 2050 based on current and stated climate policies.

Furthermore, projections of temperature rise into the future show that for the next 20 years the projected temperature increases are expected to remain nearly the same under a range of emissions trajectories (Collins et al. 2013, p. 1054). As shown in Figure 4, temperature projections only begin to diverge significantly two to three decades from the start of the modelling runs.

3 RCP stands for Representative Concentration Pathway. RCPs are scenarios used in climate modelling and IPCC assessment reports. Each pathway represents a possible trajectory for atmospheric greenhouse gas concentrations. The numbers (4.5, 8.5, etc.) refer to the amount of radiative forcing – that is the difference between the amount of solar energy absorbed by the Earth and the amount reflected back into space – that would result by 2100. RCP2.6 represents a pathway of stringent emissions reductions, in which global emissions have already begun declining by 2020. RCP8.5 would see emissions continue to rise throughout the 21st century. RCP4.5 is a middle scenario.

Figure 4: 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.



An analysis of CMIP6[4] model runs gives a similar result (CarbonBrief 2020). The four scenarios assessed (SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5)[5] all show a range of years, along with the median year, when 1.5°C is exceeded.

SSP1-2.6: 2033 (2026-2057)
SSP2-4.5: 2032 (2026-2042)
SSP3-7.0: 2032 (2026-2038)
SSP5-8.5: 2030 (2026-2039)

Under nearly all scenarios, the year in which the 1.5°C breach occurs falls between 2026 and about 2040, with only SSP1-2.6 showing a few simulations stretching out to 2057.

The median years when 1.5°C is exceeded cluster within the 2030-2033 range. Consistent with the IPCC AR5 analysis, the projected temperature rises for a wide range of emission scenarios do not diverge significantly for the first 10-20 years and the average year in which 1.5°C is exceeded is virtually identical for all emission scenarios.

The conclusion from these observations and projections is that climate change is accelerating, and for the next 10-20 years further temperature increases are likely to remain the same regardless of what happens to our emissions in the near term. All scenarios lead to a transgression of 1.5°C temperature rise around 2030 or 2035.

All emission scenarios expect 1.5°C temperature rise to be breached in the early to mid 2030s.

4 Climate models are constantly improving, incorporating higher resolutions and new elements of the Earth System. Teams of modellers coordinate their updates around the IPCC assessment cycle, releasing a set of results (known as 'runs') ahead of each assessment report. These form part of the CMIP, which stands for Coupled Model Intercomparison Project, and is an effort to synthesizes the results of the many different and increasingly sophisticated climate models. The 2013 IPCC fifth assessment report (AR5) featured climate models from CMIP5. The upcoming 2021 IPCC sixth assessment report (AR6) will feature new and considerably more advanced CMIP6 models. CMIP6 will consist of the results from around 100 climate models produced by 49 different modelling groups around the world.

5 SSP stands for Shared Socioeconomic Pathways. SSPs are used by climate modelers along with Representative Concentration Pathways – RCPs (see footnote 3). SSPs include factors such as population change, economic growth, technology development, urbanisation and education. As part of the development of the IPCC SR1.5, a new family of scenarios: SSPx-1.9 was created. These are designed to be below 1.5°C in the year 2100, though often only after exceeding it earlier in the century (so-called 'overshoot' scenarios). However, these scenarios do not consider the relatively well understood feedbacks described in chapters sections 2.3 and 2.5 of this report, as well as Appendix A. In addition, those scenarios that see overshoot and negative emissions to draw temperatures back down beneath 1.5°C by the end of the century suffer a considerable flaw: the biophysical impacts of exceeding 1.5°C are felt at the time global temperatures reach this level, and not at some arbitrary point in the future.

2.2 Committed (unavoidable) climate change

Another reality check on the feasibility of limiting global average temperature rise to no more than 1.5°C above pre-industrial levels is based on how much future warming is locked into the climate system from emissions that have already occurred. There are two different model-based approaches to estimating the warming already locked in from past emissions: (i) zero emissions, and (ii) constant concentration.

The zero emissions approach simulates the changes in the climate system when zero net CO_2 human emissions are achieved and maintained. This method shows that the global temperature stabilises quickly after zero emissions are achieved and then is maintained at about that level (MacDougall et al. 2020). This result is primarily based on two opposing processes, both of which are centred on the ocean. First, more than 90% of the increased energy in the climate system due to CO_2 emissions has been absorbed by the oceans (IPCC 2019), with only about 1% absorbed by the atmosphere (note: the remaining energy is absorbed approximately equally by land and ice.) The climate system has not yet achieved equilibrium but, when it does, there will be a net transfer of heat from the ocean to the atmosphere, driving a further increase in global temperature. The second process is the ongoing absorption of atmospheric CO_2 by the ocean. Once net zero emissions are achieved, this process leads to decreasing atmospheric CO_2 concentration, which reduces the greenhouse effect and lowers global temperature. Model simulations show that, in general, these two processes approximately offset each other, leading to a rapid and ongoing stabilisation of global temperature (MacDougall et al. 2020).

The second approach – constant concentration – is based on a stabilisation of the atmospheric CO_2 concentration at a given level, and simulating the change in global temperature that would result if that concentration were maintained into the future. The IPCC AR5 carried out this simulation, based on stabilisation of atmospheric CO_2 concentration at its 2000 level, which was about 370 ppm. The result was that global temperature continued to slowly increase through the 21st century, reaching a level in 2100 that was 0.6°C higher than the 2000 level.

More than 90% of the excess heat in the climate system has been absorbed by the oceans.

Figure 5: Large-scale thawing of permafrost in Alaska is causing "drunken forests" as the land sinks.

So which approach – net zero emissions or constant atmospheric CO_2 concentration – is better for estimating temperature rise that is already locked in?

Net zero emissions is defined as a balance between any remaining human emissions and the uptake of carbon by both natural carbon sinks in the Earth System and human-generated 'drawdown' technologies. The weakness in this approach is that it does not account for increasing carbon emissions from feedback processes within the Earth System as the climate warms. Most of these feedback processes are not yet incorporated into the models used to carry out the simulations of the climate system response. Accounting for these processes, if at all, is usually carried out by adding to the model-based results the additional warming that would occur from these carbon cycle feedback[6] processes (see Chapter 2.5 on carbon budgets below).

One of the most important feedbacks that is not included in models used to simulate 1.5°C-compatible emission reduction trajectories or net zero emissions scenarios is thawing permafrost. Recent research suggests that the off-line estimates of the size of these emissions are likely to be underestimates because of abrupt thaw

6 The carbon cycle is the collection of processes that sees carbon move through the Earth System, and exchanged between the atmosphere, ocean, and land, including organisms within them. 'Feedbacks' refers to how these processes may change as the Earth warms.

processes (Turetsky et al. 2020), which are becoming a more significant risk because of the extreme heating in the polar north (for example, Ciavarella et al. 2020). In fact, acceleration of abrupt thaw processes has already been observed over the past two decades and is expected to increase further (Lewkowicz and Way 2019). One estimate suggests that, compared to the present, three times more carbon will be exposed to abrupt thaw by 2100 under a moderate emissions scenario (RCP4.5) (Nitzbon et al. 2020). Other studies show that under moderate-to-high emissions scenarios (RCP4.5-8.5), the resulting emissions from abrupt thaw would double the projections of emissions from gradual thaw alone (Turetsky et al. 2020; Gasser et al. 2018).

These projections of increased losses through abrupt thaw would apply to emission scenarios consistent with 1.5 or 2°C targets. In fact, abrupt permafrost thaw could shift the northern hemisphere peatland from being a ‘carbon sink’ to becoming a source of carbon emissions for centuries, dominated by escaping methane (Hugelius et al. 2020). Another amplifying effect – the priming effect of permafrost thaw on soil respiration (Keuper et al. 2020) – would further increase carbon emissions. In summary, this new knowledge suggests that carbon emissions from permafrost thaw could double the current projections for 2100. Emissions could be even larger when including effects of permafrost thaw on root activity.

Abrupt thawing of permafrost could turn the the northern hemisphere peatland from a ‘carbon sink’ into a major source of carbon emissions for centuries to come.

Land carbon sinks – for example, the removal of CO_2 from the atmosphere by land ecosystems such as forests – currently remove about 30% of anthropogenic CO_2 emissions (compared to about 25% for the ocean carbon sink) (Friedlingstein et al. 2020). This rate of carbon uptake has been steady over the past several decades. The CO_2 fertilisation effect (in general, plants grow more vigorously under higher CO_2 levels) has been the primary cause (Tharammal et al. 2019; Walker et al. 2020). However, recent observations show that the CO_2 fertilisation effect is beginning to decline because of water and nutrient limitations (Wang et al. 2020). This decline is likely to become more pronounced as the climate continues to change. In addition, tropical regions, which are important carbon sinks, may be at or near sink saturation now (Hubau et al. 2020). Hubau et al. note that "...given that tropical forests are likely to sequester less carbon in the future than Earth System Models predict, an earlier date by which to reach net zero anthropogenic greenhouse gas emissions will be required to meet any given commitment to limit the global heating of Earth." More generally, observations show that as global temperature rises, photosynthesis (uptake of carbon) reaches a maximum and then declines while respiration (release of carbon) continues to increase. Observation-based projections show that, even under rapid emission reduction scenarios (for example, RCP2.6), the land carbon sink strength could reduce by 10-30% (Duffy et al. 2021).

Figure 6: Aerial view of the Amazon rainforest, Brazil. Rainforests like the Amazon are massive carbon sinks, but may be at or near sink saturation already (meaning the rate at which they take up carbon dioxide may have slowed).

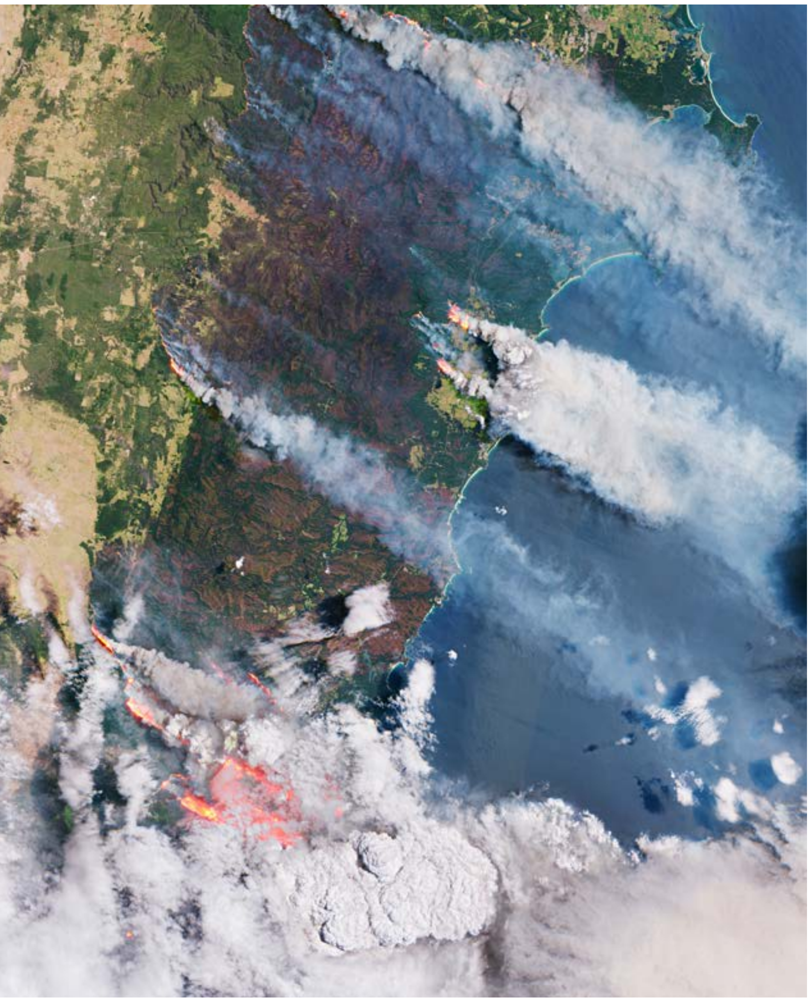
As the global average temperature rises, the uptake of carbon by plants reaches a maximum and then declines while the release of carbon from plants continues to increase.

The land sink also responds to environmental changes such as heatwaves, droughts and disturbance regimes (for example, fires) (Bastos et al. 2020), as well as to direct human deforestation and land-use change (Brando et al. 2020). Changes in disturbance regimes, such as increases in wildfires which may now be underway in Australia, California, the Amazon, and the Arctic (Bowman et al. 2020), will contribute to a net transfer of carbon from land ecosystems to the atmosphere. The bottom line is that although there is currently a substantial land carbon sink, evidence is mounting for a weakening sink capacity into the future.

Although much uncertainty still surrounds the magnitude of these effects, evidence is rapidly growing that processes that weaken the land carbon sink and emit further carbon to the atmosphere are now underway. Thus, the overall conclusion from this synthesis of recent research is that additional carbon emissions from thawing permafrost and increasing disturbance (for example, fire), coupled with the erosion of land sink capacity, means that a constant concentration scenario is more appropriate for estimating the temperature trajectory corresponding to net zero human emissions.

Although there is currently a substantial land carbon sink, processes that weaken it and emit further carbon into the atmosphere are now underway.

Figure 7: The Black Summer bushfires in 2019-2020 released a significant amount of carbon into the atmosphere. Increases in wildfires in many parts of the world will contribute to a net transfer of carbon from land ecosystems to the atmosphere.



As noted above, the IPCC AR5 constant concentration scenario was based on a CO_2 concentration at the year 2000 of about 370 ppm, stabilised at that level out to 2100, which resulted in an additional 0.6°C of warming (Collins et al. 2013, p.1103). If the same experiment were carried out from 2020, the timeframe would be shorter (80 instead of 100 years) but the stabilised CO_2 concentration would be higher (ca. 410 ppm). If we assume these effects cancel out, and there is an additional temperature rise at 2100 of 0.6°C already locked into the climate system even if CO_2 concentration is stabilised at 410 ppm, then global temperature would continue to increase slowly through the rest of this century, reaching about 1.7°C by 2100.

In summary, given that weakening of the land carbon sink and emissions from permafrost and forest disturbances are already underway, it is likely that these ongoing carbon emissions will partially or completely counteract the drawdown of CO_2 when human emissions reach net-zero. Thus, the constant CO_2 concentration model experiment described above is the more likely scenario. The conclusion from this analysis of model experiments is that cumulative emissions up to 2020 (current CO_2 concentration) will mean we breach the 1.5°C level (see Chapter 2.4).

Cumulative emissions up to 2020 may alone be enough to drive 1.5°C of warming in the long term.

2.3 Updated estimate of Equilibrium Climate Sensitivity

The equilibrium climate sensitivity (ECS) is defined as the long-term global rise in air temperature resulting from a doubling of atmospheric CO_2 concentration. The 'likely' (67% probability) ECS range was estimated in the IPCC AR5 as being 1.5-4.5°C (Collins et al. 2013). However, the World Climate Research Programme has recently carried out a new, comprehensive analysis of ECS, using multiple lines of evidence that include state-of-the-art climate models as well as palaeo-evidence from past states of the climate system (Sherwood et al. 2020). This updated analysis estimates the ECS range as 2.3-4.5°C; with the upper end of the range the same as that outlined in the IPCC AR5 report, but the lower end now assessed as very unlikely.

The implication of this update is that moderate emission reduction trajectories, which are politically and technologically more feasible, are now less likely to meet the *Paris Agreement* long-term temperature goal than previously thought. The new estimate of ECS also has implications for the carbon budget approach (see Chapter 2.5 below). When the most recent carbon budget analysis was released by the IPCC in its Special Report on Global Warming of 1.5°C (SR1.5) (2018), there were already some individual studies suggesting that low values of ECS were less likely. The IPCC SR1.5 noted that if the lower bound of ECS was revised upwards, it would decrease the chances of limiting warming to below 1.5°C in its assessed pathways. Nevertheless, the SR1.5 noted that "....it is premature to make a major revision to the lower bound" and "the tools used in this chapter employ ECS ranges consistent with the AR5 assessment." Thus, in light of the updated estimate of ECS, the IPCC SR1.5 carbon budgets are likely to over-estimate the remaining allowable emissions for a given temperature target.

2.4 Insights from past climates

The Earth System has existed in a number of climatic states in the recent geologic past, some of which have similarities to the current trajectory of the climate system in terms of greenhouse gas concentrations and temperature changes. Although there are no states that mirror the present, extremely rapid trajectory of the climate system, analysing these past climatic states can provide insights into potential conditions that we might experience in the future. An important feature of these past climatic states is that the estimated temperatures are based on equilibrium conditions, that is, after all of the feedbacks internal to the Earth System have been accounted for.

An obvious question is: when did the Earth last have atmospheric concentrations of CO_2 around 400 ppm and what was the climate like then? A recent synthesis by the Geological Society of London (Lear et al. 2020, and references therein) provides valuable insights into this question and others related to contemporary climate change.

The most recent CO_2 analogue is the mid-Pliocene, a period from 3.1 to 3.3 million years ago when atmosphere CO_2 concentration was in the range from 331 to 389 ppm, the upper estimate being slightly lower than today's concentration. Earth's continental configuration and the topography of the ocean floor were similar to today. Global average temperatures in the mid-Pliocene were similar to the range predicted for 2100 for a business-as-usual scenario: 2.6 to 4.8°C compared to pre-industrial temperatures. Sea levels may have reached 20 metres higher than today. There were reduced polar ice sheets, a poleward shift of land biomes, and weaker atmospheric and ocean circulation.

The current speed of human-induced climate change is nearly without precedent in almost all the geological past. The only known exception was when a meteorite wiped out non-bird-like dinosaurs 66 million years ago.

Another useful analogue, particularly for present day rates of change, is the Paleocene-Eocene Thermal Maximum (PETM), a rapid temperature increase of about 5-6°C (up to 8°C at the poles) that occurred about 56 million years ago. The cause was the injection of several billion tonnes of carbon into the atmosphere by volcanic eruptions and metamorphism of organic-rich sediments. The PETM resulted in 12-15 metres of sea-level rise, ocean acidification and deoxygenation, and large changes in the terrestrial biosphere and the water cycle. At the most rapid rate, about 0.6 billion tonnes of carbon per year was emitted to the atmosphere. By comparison, human emissions of carbon are currently about 11 billion tonnes per year (about 40 billion tonnes of CO_2). The Earth System eventually recovered to its pre-PETM state, but the recovery took 100,000 - 200,000 years as CO_2 was slowly removed from the atmosphere by chemical weathering of silicate and carbonate minerals.

The most striking insight from the palaeo-evidence comes from comparing the current rate of change to past rates of change in the Earth System. As the Geological Society of London (Lear et al. 2020, p. 1) notes:

> *"...the current speed of human-induced CO_2 change and warming is nearly without precedent in the entire geological record, with the only known exception being the instantaneous, meteorite-induced event that caused the extinction of non-bird-like dinosaurs 66 million years ago. In short, whilst atmospheric CO_2 concentrations have varied dramatically during the geological past due to natural processes, and have often been higher than today, the current rate of CO_2 (and therefore temperature) change is unprecedented in almost the entire geological past."*

2.5 Carbon budget analysis

An analysis based on the 'carbon budget' approach also provides evidence that limiting global warming to 1.5°C above pre-industrial levels without significant overshoot and subsequent drawdown will be impossible.[7] The carbon budget approach is a conceptually simple, yet scientifically robust, approach to estimating the level of greenhouse gas emission reductions required to meet a desired temperature target (Allen et al. 2009; Meinshausen et al. 2009). The approach is based on the approximately linear relationship between (i) the cumulative amount of CO_2 emitted from all human sources since the beginning of industrialisation (often taken as 1870, consistent with the 1850-1900 average temperature baseline); and (ii) the increase in global average surface temperature (Figure 8; Collins et al. 2013; IPCC 2018). Once the carbon budget has been 'spent' (emitted), then emissions need to be net zero[8] to avoid exceeding the corresponding temperature target.

The IPCC SR1.5 (2018) applied the carbon budget approach to the 1.5°C and higher temperature targets, with the budget beginning from 1 January 2018, rather than from the beginning of the industrial revolution, as shown in Figure 8.

As shown in Table 1, we apply the IPCC SR1.5 budget approach to explore the feasibility of restricting temperature rise to no more than 1.5°C, starting from the beginning of 2021 (but note Chapter 2.3 above on ECS). For this report we chose a 67% probability of meeting the temperature target.

7 The carbon budget approach is based on achieving a desired temperature target without overshoot and subsequent drawdown.

8 "Net zero emissions" means the magnitude of CO_2 emissions to the atmosphere is matched by the magnitude of CO_2 removal from the atmosphere by, for example, natural processes as well as carbon capture and storage (CCS) technologies, sometimes called "Negative Emission Technologies". At present these technologies are in the early development stage, and none are technologically or commercially viable yet at the scale needed to significantly influence the carbon budget.

Figure 8: Temperature change since pre-industrial levels (1850-1900 average) associated with cumulative CO_2 emissions since 1st January 1876. Further details on the figure are given in the caption to Figure 2.3 in IPCC (2018).

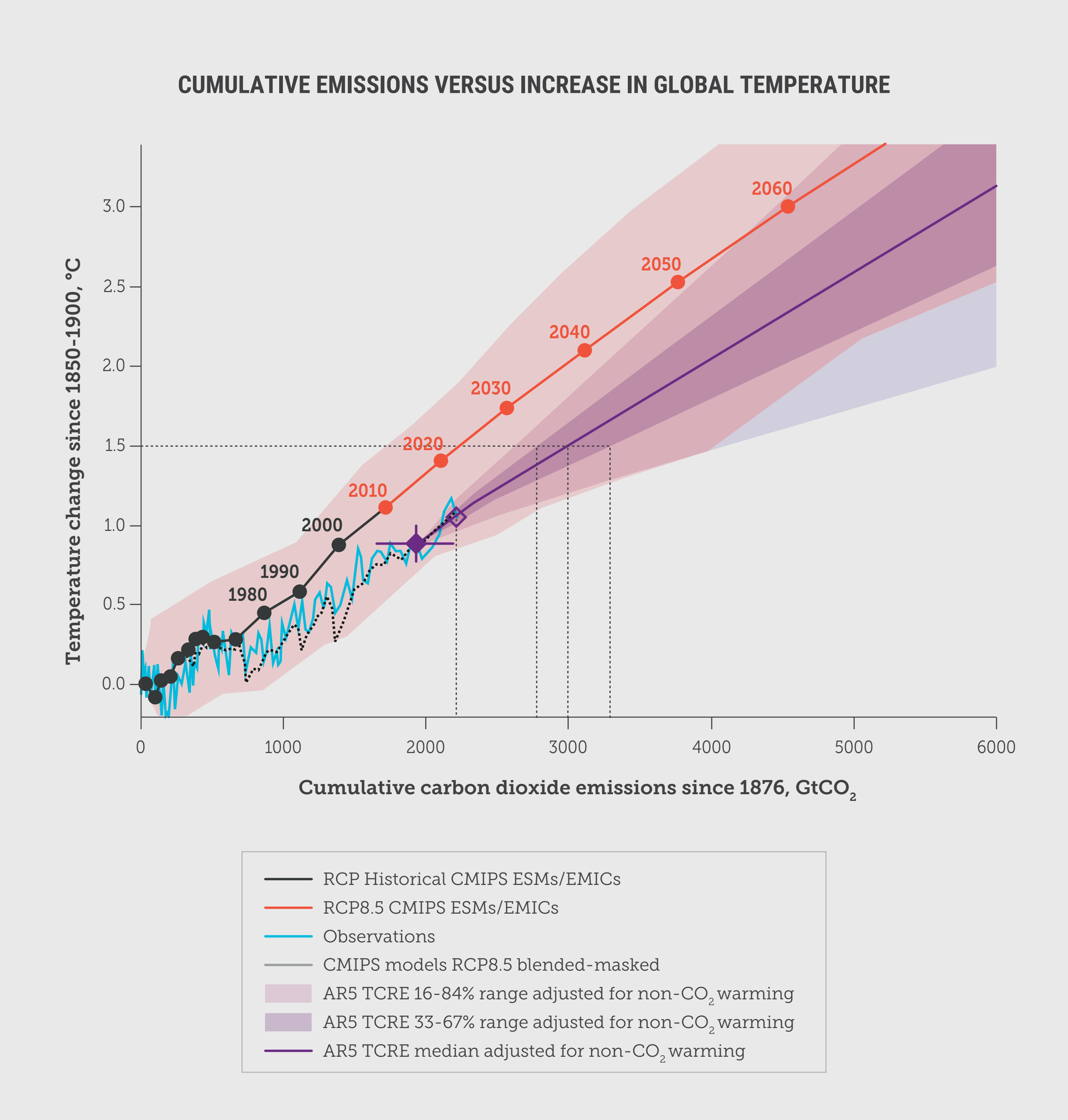


Table 1: Global carbon budget for a 67% probability of restricting temperature rise to no more than 1.5°C, based on the IPCC SR1.5 approach (IPCC 2018).

Budget Item/Process	Gt CO_2 (gigatonne of carbon dioxide)
Base budget from 1 Jan 2018[9]	570
Accounting for non-CO_2 greenhouse gases (Estimated from Table 2.2 of IPCC SR1.5 (2018), see Appendix A)	-90
Historical emissions for 2018, 2019 and 2020 (Friedlingstein et al. 2020)	-125
Carbon cycle feedbacks (IPCC 2018; Steffen et al. 2018; see Appendix A for details)	-245
Remaining budget to net zero emissions	110

The current (pre-COVID-19) rate of human emissions of CO_2 is about 43 Gt CO_2 per year (Friedlingstein et al. 2020), so the remaining 1.5°C budget of 110 Gt CO_2 means that we have about 2.5 years of emissions left at current rates (Table 1; Box 2). This carbon budget is strongly influenced by estimates of two key uncertainties: (i) the rate at which non-CO_2 greenhouse gases are reduced, and (ii) the size of carbon cycle feedbacks, such as melting permafrost, which emit greenhouse gases to the atmosphere (see Appendix A for details). In Table 1, these factors reduce the budget by 335 Gt CO_2.

Assuming a linear rate of emission reduction starting from the end of 2020, this budget would be consumed in about five years, around the middle of this decade (Box 2). Clearly it is not possible – technologically, economically or politically – to stay within the budget of Table 1 under any scenario (UNEP 2019; Climate Action Tracker 2020). Building in less likely assumptions including that non-CO_2 greenhouse gases are reduced at the same rate as CO_2, and ignoring carbon cycle feedbacks other than permafrost (see Box 2), means that we end up with a more generous budget of 345 Gt CO_2, which would give us until 2036 to reach net zero globally based on a linear rate of emission reduction. This means that we would have to reduce emissions by about 2.2 Gt CO_2 per year until net zero is achieved. By comparison, the COVID-19 crisis is projected to reduce emissions in 2020 by 1.8-2.9 Gt CO_2 (Le Quéré et al. 2020). This would still mean that we would have to reduce emissions continuously year after year at about the same rate as they were reduced by the COVID-19 response in the past year. Current realities, including the observation that many countries are already showing a rebound in emissions as they emerge from COVID-19 restrictions (IEA 2021), make it highly unlikely in the absence of specific new initiatives to dramatically decarbonise all major emitting sectors of the global economy.

9 This base budget is calculated assuming an observed temperature rise of 0.87°C from the pre-industrial period to the 2006-2015 base period. If a rise of 0.97°C for this period is used as the basis of the budget, the remaining budget from 1 January 2018 would be 420 Gt CO_2, and would already be exhausted based on the analysis of Table 1. Using a 420 Gt CO_2 base budget and including only historical emissions and the IPCC estimate of Earth System feedbacks (100 Gt CO_2) would give a remaining budget of 195 Gt CO_2, which would be exhausted in 4.5 years at current rates.

BOX 2: DESCRIBING CARBON BUDGETS

Carbon budgets can be described in various ways, yielding different values for the time remaining before the budget is consumed and net zero emissions must be achieved. The visual representations below, for the global carbon budget of Table 1, explain how the same carbon budget can be interpreted in different ways, giving different years for achieving net zero emissions.

The area of the shapes in both figures is the same, and represents the cumulative emissions remaining before net zero must be achieved – the remaining carbon budget. The budget is thus the same, but the way it is described differs. In Figure 9, emissions are maintained at a constant level until the budget is exhausted. In Figure 10 – the more common approach and the one used by the Climate Targets Panel (2021) – emissions are reduced linearly until net zero is achieved and the budget is exhausted. Other shapes of the emission reduction trajectory could be drawn, but the area under the line/curve must always be the same, equivalent to the carbon budget.

Changes in the assumptions made in formulating the budget will change the size of the remaining budget, and hence the speed of emissions reductions required to remain within the budget, as shown in Figure 11.

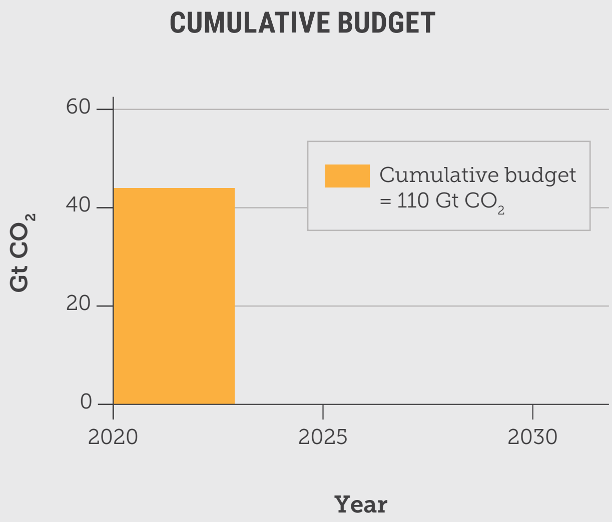


Figure 9: Time remaining at the current emission rate before a carbon budget for a 67% probability of restricting temperature rise to no more than 1.5°C is exhausted: about 2.5 years.

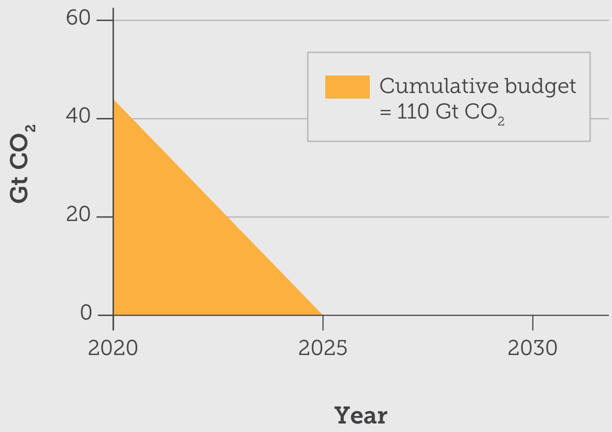


Figure 10: Time remaining at a linear rate of emission reduction before a carbon budget for a 67% probability of restricting temperature rise to no more than 1.5°C is exhausted: about 5 years.

BOX 2: *CONTINUED*

(i) The yellow wedge is the same as in Figure 10 above. The cumulative budget is 110 Gt CO_2.

(ii) The orange wedge represents a larger (riskier and less realistic) cumulative budget (345 Gt CO_2), created by ignoring all feedbacks except permafrost and assuming that non-CO_2 gases (CH_4 and N_2O) would be reduced at the same rate as CO_2. Under such a budget, emissions would need to reach net zero by 2036 at a linear rate of emission reduction (see Appendix A for more detail on the treatment of feedbacks and non-CO_2 greenhouse gases in the carbon budget). Budget forecasts can also vary depending on what probability of reaching/ breaching particular temperature targets is chosen (for example, 50% probability instead of 67%).

(iii) We could create a more conservative budget by assuming that emissions of CH_4 and N_2O would not be reduced from their 2020 levels and that we have underestimated the strength of carbon cycle feedbacks. Doing this would show that any budget for a 67% probability of restricting temperature rise to no more than 1.5°C has already been exhausted.

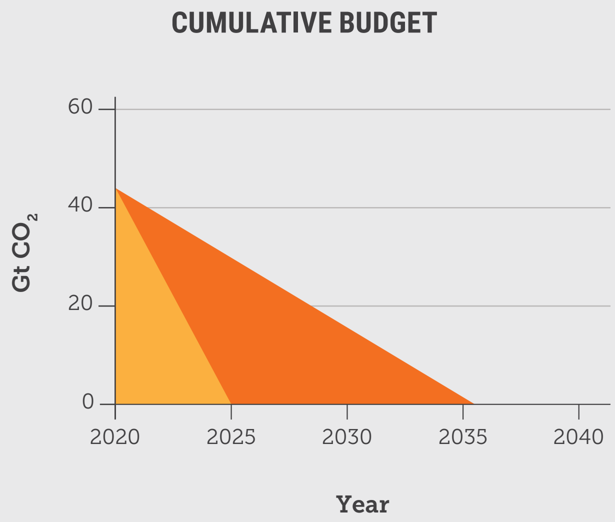
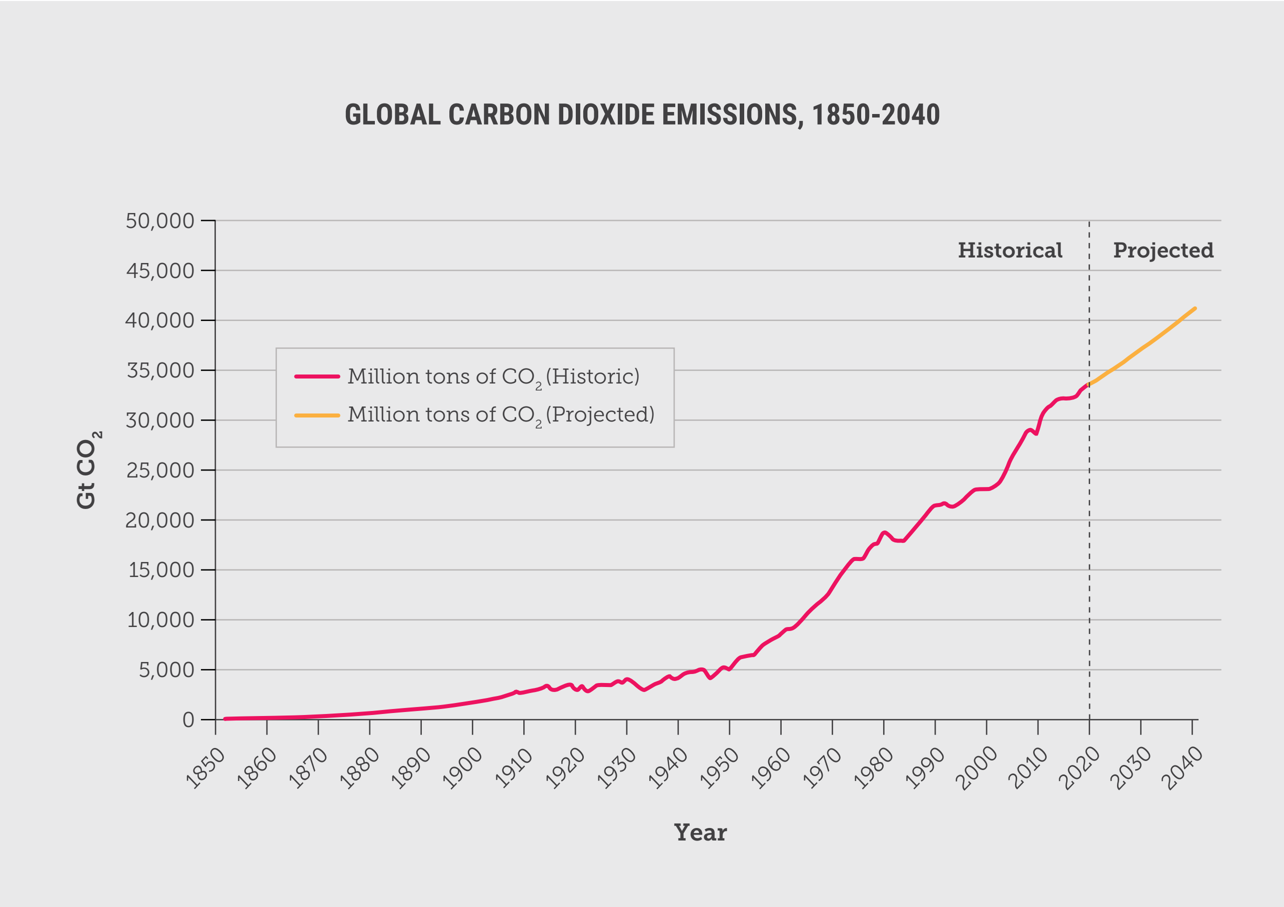


Figure 11: Two different carbon budgets for a 67% probability of meeting a 1.5°C target. The budgets differ in assumptions made about carbon cycle feedbacks and reduction of non-CO_2 gases.

The impossibility of staying under 1.5°C without overshoot and then drawdown becomes even more apparent from a comparison with the historic record of emissions, as shown in Figure 12. Despite a few minor drops, there has been an increasing rate of CO_2 emissions from the mid-20th century. This trend would have to stop immediately and plunge rapidly to near zero in just five or six years to remain within a global carbon budget for a 67% probability of restricting temperature rise to no more than 1.5°C.

Any further delay in reducing our emissions will dramatically affect the outcome. If we delay our steep emission reduction trajectory by only three years, emitting about 42 Gt CO_2 per year, our remaining budget is reduced by about 126 Gt CO_2. This delay eliminates the 110 Gt CO_2 budget calculated above, and reduces our more generous budget to 219 Gt CO_2, which leaves us only five years of emissions at our assumed reduced rate of 42 Gt CO_2/yr before the more generous budget for a 67% probability of restricting warming to 1.5°C is breached. The conclusion is clear: a delay of only three years in reducing emissions makes even our more generous 1.5°C budget impossible to meet.

Figure 12: CO_2 emissions from 1850 to 2040. **Source:** Data from Carbon Dioxide Information Analysis Center (Oak Ridge National Laboratory, 2017) and the World Energy Outlook (International Energy Agency, 2019), adapted from Centre for Climate and Energy Solutions (2020).



Any delay in reducing our emissions will dramatically affect the outcome. If we delay by only three years, even our more generous 1.5°C budget would become impossible to meet.

The analysis above is based only on the maths of the carbon budget approach, without considering the likelihood of concerted global action to meet the very stringent budget. When this is considered, the impossibility of meeting any realistic 1.5°C budget becomes even clearer, as does the daunting challenge of keeping temperature rise to well below 2°C.

Australia is a prominent example of ineffective action. Australia is the world's fifth largest emitter of greenhouse gases when counting our exported emissions as well as our domestic emissions. Even when our exports are ignored, Australia ranks in the top 20 emitters globally.

The commitments Australia made under the *Paris Agreement* are extraordinarily weak – both in comparison to most other countries and in light of the science. Furthermore, following the abolition of the carbon price in 2014, all progress in reducing Australia's total emissions stalled (Australian Government 2020b). Scientific advice has been systematically ignored by politicians and some industries, and effective initiatives such as the Australian Renewable Energy Agency (ARENA) and the Climate Commission have been weakened or abolished. Not only is the Federal Government failing to reduce emissions, it is actively adding to the problem by supporting the expansion of the fossil fuel industry (for example, Technology Investment Roadmap, Australian Government 2020a). Such decisions are being taken while Australians are increasingly being harmed by worsening climate impacts such as the catastrophic bushfires of 2019-2020 and repeated mass bleaching of the Great Barrier Reef (Climate Council 2019b; 2020a).

Figure 13: The Great Barrier Reef has suffered three mass bleaching events in recent years (2016, 2017 and 2020) resulting in catastrophic loss of corals and the species they support.

The strong climate policies of US President Joe Biden, along with a significant number of countries that have already pledged to reach net zero emissions by 2050 (or 2060 in the case of China), are encouraging, and build momentum for more effective climate action at the global level. However, far more ambitious targets than net zero by 2050, and action to back them up, will be required to hold warming to well below 2°C. The most important test is the level of ambition for 2030. Stronger targets, plans and actions for this decade are the immediate imperative. A growing number of countries have now strengthened their targets for 2030 or signalled that they intend to do so. However, very few have set 2030 targets that are consistent with the *Paris Agreement*'s long-term temperature goal.

What Australia does on climate change will make a world of difference. We are among the top 20 biggest polluters in the world, and if you count our exports we're the fifth largest.

2.6 Conclusion

The science is clear. Multiple lines of evidence – observed and committed temperature rise, insights from recent science advances as well as from past climates, a carbon budget analysis, and the large gap between actual efforts to reduce emissions and what is required – tell us it is now impossible to limit global average temperature rise to 1.5°C without substantial overshoot. This conclusion was echoed in a recent open letter (see Appendix B) from 25 of Australia's top climate scientists to former Chief Scientist Dr Alan Finkel:

> *"At this point it would take a global social, political and technological miracle to keep the world under 1.5°C."*

This conclusion was also underscored in an update of the Climate Change Authority's 2014 advice regarding Australia's Paris targets (Climate Targets Panel 2021). Using the same methodology as the original 2014 approach to determine the emission reduction targets required for Australia to do its fair share to tackle the climate crisis, this update report determined that for only a 50% chance of meeting the 1.5°C target, Australia would need to reduce its emissions by 74% below 2005 levels by 2030 and reach net zero emissions by 2035. The Panel further noted:

> *"The report relies on published carbon budget analysis to model only a 50% chance of remaining below 1.5°C, and does not consider what, if any, budget is left to achieve a 67% chance of remaining below 1.5°C."*

The IPCC SR1.5 Report describes the challenge in limiting temperature rise to 1.5°C (IPCC SR1.5, Summary for Policy Makers C2, p. SPM-21):

> *"Pathways limiting global warming to 1.5°C with no or limited overshoot would require rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems. These systems transitions are unprecedented in terms of scale, but not necessarily in terms of speed, and imply deep emissions reductions in all sectors, a wide portfolio of mitigation options and a significant upscaling of investments in those options".*

Now, three years after the publication of the IPCC SR1.5 (2018) and six years after the *Paris Agreement* (2015), the "....rapid and far-reaching transitions", or even planning for such transitions, are not yet underway. Thus, it might now be appropriate to add that the systems transitions required are likely to be unprecedented in terms of speed as well as scale.

Multiple lines of evidence tell us it is now impossible to limit global average temperature rise to 1.5°C without substantial overshoot.

3. What's at stake: a world of difference between 1.5°C and 2°C

In principle, the global average temperature rise could eventually be returned to 1.5°C or below after a period of 'overshoot' (going above 1.5°C) followed by drawdown of CO_2 from the atmosphere. One oft-cited drawdown approach is carbon dioxide removal (CDR), using methods such as increasing forest cover, land restoration and soil carbon sequestration. Another approach is bioenergy and carbon capture and storage (BECCS). Ecosystem restoration is an essential part of responding to climate change and must be pursued as part of efforts to limit warming. However, in general, drawdown techniques cannot currently be rolled out on the large scale required, and for many, their feasibility and sustainability have not been proven (IPCC 2018).

Overshooting 1.5°C means that the impacts of hitting higher temperatures would still be felt across societies and ecosystems, even if the temperature could eventually be reduced via drawdown. The risks of tipping points being crossed would also be higher during the overshoot period (see Chapter 4 below). Here, we unpack the implications of a 1.5°C world versus a 2°C world, highlighting why every fraction of a degree matters.

The IPCC's Special Report on Global Warming of 1.5°C (2018) warned that allowing the planet to warm by more than 1.5°C above pre-industrial levels would have grave consequences. For example, failure to limit global warming to no more than 1.5°C elevates the risks to marine biodiversity, fisheries, and ecosystems, with consequences for human well-being. At a temperature rise of 1.5°C, coral reefs "are projected to decline by a further 70-90 percent", and tropical reef-building corals are projected to "mostly disappear" at 2°C (IPCC 2018). Since 2016, the Great Barrier Reef has suffered three mass bleaching events (2016, 2017 and 2020) (JCU 2020), resulting in catastrophic loss of corals and the species they support. These losses have serious economic consequences, given that the Great Barrier Reef has been estimated to directly support 64,000 Queensland workers and generate more than $6 billion for the Australian economy (Deloitte Access Economics 2017).

Figure 14: Mangrove forests in the Gulf of Carpentaria are one of the Australian ecosystems in the process of collapse, with climate change being a factor.

Many other Australian ecosystems are under immense strain due to climate change, with impacts set to worsen as the temperature climbs. A recent study found that 19 Australian marine and terrestrial ecosystems, ranging in latitude from tropical reefs to old growth moss 'forests' in the Australian Antarctic Territory, are undergoing collapse, with climate change a factor in almost all cases (Bergstrom et al. 2021).

A 2°C temperature rise, compared to 1.5°C, will significantly increases the likelihood of many impacts in Australia related to extreme events: heatwaves, power blackouts, bushfires, floods, water restrictions and reduced crop yields (King et al. 2017) (see Figure 17).

The accelerating rise in global sea levels is already causing significant coastal erosion and exacerbating damage from storm surges. A temperature increase of 2°C, compared with 1.5°C, will potentially expose 10.4 million more people globally to coastal impacts. Sea levels will continue to rise beyond 2100, with risks of instabilities in the Greenland and Antarctic ice sheets causing "multi-metre" increases in sea levels in the centuries and millennia to come (IPCC 2018).

Rising sea levels directly threaten critical infrastructure and major population centres in Australia, including Sydney, Melbourne, Adelaide and Perth (Climate Council 2014). The northern Australian and Queensland coastlines are particularly vulnerable, including regional centres such as Darwin and Townsville (Kirezci et al. 2020) and natural icons such as the World Heritage-listed Kakadu National Park (Climate Council 2019a). In 2020, New South Wales suffered a series of severe and compounding coastal erosion events, including along Sydney's northern beaches, the Central Coast, and the Northern Rivers (Climate Council 2021). We can expect such events to be more frequent and severe with every tenth of a degree of further warming, and to be significantly more costly at warming of 2°C, compared to 1.5°C.

Food security will be significantly reduced at a 2°C temperature rise compared to 1.5°C as increases in extreme weather and rising atmospheric CO_2 affect crop nutrient content and yields, livestock health, fisheries and aquaculture, and land use (cover type and management).

In the world's most vulnerable countries and regions, changing rainfall patterns, accelerating sea-level rise and worsening extreme events such as heatwaves will escalate the risks of starvation, mass human migration and conflict. Some agricultural zones will likely collapse and significant amounts of coastal infrastructure will be inundated.

The impacts that we are experiencing now at around a 1.1°C rise in average temperature (Box 3) are forerunners of rapidly escalating risks as global temperatures rise towards 2°C and beyond. Time is rapidly running out for humanity to avoid the extremely serious risks of a 2°C or warmer world.

Figure 15: Flooding of the North Richmond Bridge, NSW, 2021.

IMPACTS AT 1.5°C AND 2°C OF WARMING

DIRECT IMPACTS	1.5°C	2°C	2°C IMPACTS
EXTREME HEAT Global population exposed to severe heat at least once every five years	14%	37%	2.6X WORSE
SEA-ICE-FREE ARCTIC Number of ice-free summers	AT LEAST 1 EVERY 100 YEARS	AT LEAST 1 EVERY 10 YEARS	10X WORSE
SEA LEVEL RISE Amount of sea level rise by 2100	0.40 METERS	0.46 METERS	0.06m MORE

SPECIES	1.5°C	2°C	2°C IMPACTS
SPECIES LOSS: VERTEBRATES Vertebrates that lose at least half of their range	4%	8%	2X WORSE
SPECIES LOSS: PLANTS Plants that lose at least half of their range	8%	16%	2X WORSE
SPECIES LOSS: INSECTS Insects that lose at least half of their range	6%	18%	3X WORSE

LAND	1.5°C	2°C	2°C IMPACTS
ECOSYSTEMS Amount of Earth's land area where ecosystems will shift to a new biome	7%	13%	1.86% WORSE
PERMAFROST Amount of Arctic permafrost that will thaw	4.8 MILLION KM²	6.6 MILLION KM²	38% WORSE
CROP YIELDS Reduction in maize harvests in tropics	3%	7%	2.3X WORSE

OCEANS	1.5°C	2°C	2°C IMPACTS
CORAL REEFS Further decline in coral reefs	70–90%	99%	UP TO 29% WORSE
FISHERIES Decline in marine fisheries	↓ 1.5 MILLION TONNES	↓ 3 MILLION TONNES	2X WORSE

Figure 16: The difference in projected climate impacts between 1.5°C and 2°C of warming. **Source:** IPCC 2018.

BOX 3: HITTING HOME – THE COSTS OF CLIMATE INACTION IN AUSTRALIA

Already, at around 1.1°C of global warming, Australia and the world are suffering significant losses from climate change, with worse to come.

2019-20 was an exceptionally intense period of extreme weather, capping off a decade in which the climate crisis hit hard. An extraordinary run of events, including unprecedented fire seasons in Australia and the US, a record-breaking North Atlantic hurricane season, the worst Asian monsoon floods in decades, and an astonishing series of heat records around the world, paint a sobering portrait of our escalating climate crisis (Climate Council 2021).

While no country or community is immune to the impacts of climate change, Australia is particularly vulnerable among developed countries. The cost of extreme weather disasters in Australia has more than doubled since the 1970s, reaching $35 billion for the decade 2010-2019 (Climate council 2021). Extreme heat is on the rise and rainfall patterns are changing, with the major agricultural zones in the southwest and southeast of the continent experiencing long-term drying trends in the cool season (Climate Council 2020a). An unimaginable three billion animals were killed or displaced during the 2019-20 Black Summer fires (WWF 2020). No sooner had the fires eased than the Great Barrier Reef suffered its third mass bleaching event in just five years, causing catastrophic, irreversible damage (Hughes et al. 2018a, b; 2019; JCU 2020).

Some of these recent extreme events show 'tipping point' behaviour, when a critical level of heat or drought triggers a massive, devastating event. For example, during the massive Black Summer fires, we may have crossed a tipping point for Australia's temperate broadleaf and mixed forests (Boer et al. 2020; Climate Council 2021, p. 24-26). In any typical fire season, 2-3% of these forests burn, but during the Black Summer 21% burned. Coral bleaching is another clear example of a tipping point being transgressed. There were virtually no mass bleaching events up until the 1990s, when the Great Barrier Reef suffered significant bleaching in 1998 and 2002 (Hughes et al. 2018b). 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. Extensive and damaging mass bleaching events occurred on the Great Barrier Reef in 2016 and 2017, and these were followed by the aforementioned event in March 2020. The latest event was the first time that significant bleaching occurred along the entire 2,300-km length of the Great Barrier Reef. The result of these events has been the loss of about half of all hard corals on the Great Barrier Beef.

While Australia is especially vulnerable among the world's developed countries, for our neighbours in the Pacific, the impacts of climate change are even more immediate and profound. While 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 greater (Climate Council 2021). Vulnerable coastal communities and low-lying states are already suffering increased coastal flooding, often exacerbated by tropical cyclones that are increasing in intensity (Kirezci et al. 2020).

Ignoring climate change is deadly. Its impacts are already being measured in lives lost, livelihoods destroyed, the collapse of ecosystems, and people being displaced from their land and homes. Every tenth of a degree of warming matters. Warming of 1.5°C will bring significantly worse impacts than are being seen today, and warming of 2°C far worse still (Figure 16 and 17). We must make every possible effort to minimise future warming, while also working to build the resilience of our communities and ecosystems to the impacts that can no longer be avoided.

BOX 3: *CONTINUED*

Examples of the likelihoods in a given year of similar events to four recent Australian extremes in a natural world, the current world, a 1.5°C world and a 2°C world. For the Australian drought case, changes in the likelihood of both precipitation deficits and high temperatures are considered due to their relevance. The best estimate is shown with the 5th-95th percentile confidence intervals in parentheses. Several of the impacts of each extreme event are highlighted.

For a deeper analysis of the impacts of climate change that we are already experiencing, see Climate Council's report [Hitting Home: The compounding costs of climate inaction.]

INCREASING LIKELIHOOD OF EXTREME EVENTS WITH HIGHER WARMING

Event		Associated Impacts	Natural	Current	1.5°C	2°C
Angry summer 2012-2013		Severe heatwaves, Power blackouts, Bushfires, Illnesses and deaths up	**3%** (1-5%)	**44%** (36-52%)	**57%** (50-65%)	**77%** (70-84%)
Coral Sea heat JFM 2016		Worst coral bleaching event on record	**0%** (0%)	**31%** (22-40%)	**64%** (53-76%)	**87%** (79-93%)
SE Australia drought 2006	Low rainfall	Water restrictions, Less food grown	**1%** (1-2%)	**2%** (1-3%)	**3%** (1-4%)	**3%** (1-4%)
	High temperatures		**1%** (0-1%)	**35%** (28-42%)	**52%** (45-59%)	**74%** (67-81%)

Figure 17: The changing likelihood of Australian extreme events. **Source:** King et al. 2017.

4. The magnitude of the challenge and the Australian contribution needed to limit warming to well below 2°C

Limiting warming to 1.5°C without overshoot and drawdown is now out of reach due to past inaction (Chapter 2). However, it is critical that we hold warming to well below 2°C, given the extraordinary risks that we face if we don't (Chapter 3).

We can apply the same global carbon budget approach (Chapter 2) to assess the feasibility of holding warming to well below 2°C, which we assume here to be approximately 1.8°C. The calculations are shown in Table 2 below. The analysis is very similar to that carried out for the 1.5°C target, but the strength of carbon cycle feedbacks and the additional warming from non-CO_2 greenhouse gases have been scaled up to be compatible with a temperature rise of 1.8°C instead of 1.5°C (note: including carbon cycle feedbacks results in a more stringent carbon budget than that calculated by the Climate Targets Panel 2021).

Table 2: Global carbon budget for a 67% probability of restricting temperature rise to 'well below 2°C', based on the IPCC SR1.5 approach (IPCC 2018).

Budget Item/Process	Gt CO_2 (gigatonne of carbon dioxide)
Base budget from 1 Jan 2018[10]	1,020
Accounting for non-CO_2 greenhouse gases (Estimated from Table 2.2 of IPCC SR1.5 (2018), see Appendix A)	-110
Historical emissions for 2018, 2019, and 2020 (Friedlingstein et al. 2020)	-125
Carbon cycle feedbacks (IPCC 2018; Steffen et al. 2018)	-300
Remaining budget to net zero emissions	485

Limiting warming to well below 2°C is achievable but requires immediate, deep and sustained emissions reductions. Reaching 100% renewable electricity by 2030 is the first step.

The current rate (pre-COVID) of global emissions of CO_2 is about 43 Gt CO_2 per year (Friedlingstein et al. 2020), so the remaining 'well below 2°C' budget of 485 Gt CO_2 means that the world has about 11 years of emissions left at current rates. Or, if we assume a linear reduction in emissions, the world must halve emissions globally by 2032 and achieve net zero emissions by about 2043 to remain well below 2°C (Box 2).

This is achievable, but only by a sustained, long-term downward trend in global emissions, starting immediately. Reaching 100% renewables for electricity generation by 2030 – which is technically feasible – would be the first step. Electrifying other sectors like transport can also help achieve a 50% reduction by 2032, laying the foundation for the further reductions required in the following years.

This budget is global in scale so it needs to be translated into targets for Australia. In 2014 the Climate Change Authority (CCA) carried out such an analysis to provide advice to the Australian Government on our targets for the 2015 Paris UNFCCC meeting (Climate Change Authority 2014). The CCA, using a 'modified contraction and convergence' method that accounts for our current high per capita emissions as our starting point, calculated that Australia's emissions should be reduced by 45 to 65% on 2005 levels by 2030. This approach generously allocated 0.97% of the remaining global carbon budget to Australia even though our population is about 0.33% of the global total.

10 This base budget is calculated assuming an observed temperature rise of 0.87°C from the pre-industrial period to the 2006-2015 base period. The budget for a 1.8°C temperature rise was estimated by interpolation between the estimates for the 0.9 and 1°C temperature rises above the 2006-2015 base period (IPCC 2018).

To play its fair part in the rapid, sustained emissions reductions required globally, Australia should aim to reduce its emissions by 75% below 2005 levels by 2030, and to net zero by 2035.

We can apply the 2014 CCA methodology to estimate Australia's share of the remaining carbon budget in Table 2. The analysis gives a remaining Australian budget of about 4.7 Gt CO_2, which would be exhausted at Australia's current annual emission rate of over 0.5 Gt CO_2 (530.5 Mt CO_2)[11] in less than a decade. If emissions were reduced at an even rate, we would need to achieve net zero emissions in 16 years, that is, around 2038.

Other estimates of a remaining global emission budget for a 1.8°C temperature target, and Australia's share of it, could be made, but the budgets are significantly influenced by assumptions such as the size of carbon cycle feedbacks and the amount of non-CO_2 greenhouse gas and aerosol emissions. For example, if the budget of Table 2 was increased by ignoring the effects of non-CO_2 greenhouse gases and carbon cycle feedbacks, our share of the much larger global budget would be about 8.7 Gt CO_2 using the 2014 CC methodology. However, our share would be only about 3.5 Gt CO_2 if based on our population size. This budget, if emissions were reduced linearly from the beginning of 2021, would require a 65% reduction by 2030 and net zero emissions by 2035.

Although many additional carbon budgets for a 1.8°C target could be constructed, for the most likely sets of assumptions, the global emissions reduction target for 2030 would lie between 50 and 75% and net zero emissions would have to be achieved by 2035-2040.

Setting and meeting such an ambitious target would ensure that Australia played its part in the rapid, sustained reductions in global greenhouse gas emissions required to limit warming to well below 2°C. In fact, Australia's position as a wealthy country, with one of the highest per capita emission rates, means that to do our fair share, we should do better than the global average in emission reductions. An emissions target for Australia of 75% below 2005 levels by 2030, and reaching net zero emissions by 2035 (Appendix C), is consistent with global efforts to limit warming to 1.8°C.

There is no doubt that achieving a 75% reduction in Australia's emissions by 2030 is exceptionally challenging, and it will necessarily be disruptive in many ways. However, this target is scientifically robust and ethically responsible. Such steep emission reduction curves are the inevitable result of decades of delay and inaction, particularly the most recent decade.

There are several other lines of argument that support such an ambitious target.

11 For the calendar year 2019, Australia's total emissions were 530.5 Mt CO_2 (Australian Government 2021).

A 75% emission reduction by 2030 is only 10% higher than the upper end of the CCA's 2014 recommended range (45-65%) leading into the Paris summit. Given that our emissions have actually risen since the Paris meeting and the risks and impacts of climate change are becoming more obvious and severe - repeated bleaching of the Great Barrier Reef and the Black Summer bushfires, for example - a more ambitious upper target is justified.

As noted above, the rapid development of renewable energy technologies and the steep drop in their costs over the last few years make it not only feasible but very desirable to decarbonise our electricity sector by 2030. Not only would this directly lead to significant reductions in emissions, it would also support further emission reductions through the electrification of other sectors such as transport and heating/cooling. An ambitious 2030 target would provide even further stimulus to this sector, including the development of a renewables-based energy export industry.

Reducing the risks of severe impacts will take time, given the momentum in the climate system, but it can only be achieved by rapid and deep reductions in global emissions, with Australia playing a leading role in this effort. This will also reduce the risk of crossing tipping points, several of which could be transgressed in the next few decades without rapid emission reductions now. As one of the more vulnerable nations, Australia should be a leader, not a laggard.

Figure 18: Ausralia's abundant renewable energy potential can enable us to rapidly decarbonise many sectors of the economy, including transport.

An additional important consequence of the global carbon budget analysis for the well-below-2°C target is the 2043 date, and earlier in Australia's case, at which net zero emissions must be achieved. This is in contrast to the rapidly growing number of jurisdictions and organisations committing to achieve net zero emissions by 2050. This is too late if we are to avoid the devastating consequences of 2°C, or more, of global warming. The only way to do so is to at least halve global greenhouse gas emissions by 2030 and eliminate nearly all of them by 2040, reaching net zero by 2043 at the latest. (See also analysis in Climate Targets Panel report, 2021.)

Setting 2050 targets fails to 1) address the urgency of this situation, and 2) ensure that the immediate action that's required this decade is achieved. In essence, delaying climate action is as bad as denying climate change science because the outcome is the same: we fail to avoid the far more severe impacts experienced at higher levels of warming.

In summary, when all of the carbon budgets are crunched and all of the national pledges are rolled out, the concrete steps that all decision makers take in the 2020s matter the most.

The concrete steps that all decision makers take in the 2020s matter the most in terms of avoiding the most severe impacts of climate change.

5. The catastrophic risks of temperature rise beyond 2°C

The impacts that are likely to occur with warming beyond 2°C extend from very severe to catastrophic. Here we unpack the futures we might face if we allow the global average surface temperature to transgress the 2°C level. First, we describe what Australia might look like in a 3°C warmer world, drawing on a recent Australian Academy of Science report on that topic. Then we explore the rapidly growing risk of triggering tipping elements in the Earth System, which would accelerate climate change and, in a worst-case scenario, take the trajectory of the system out of any possible human control.

5.1 Australia in a 3°C world

If all the existing *Paris Agreement* emission reduction commitments pledged by countries around the world, including Australia, were implemented on time, the Earth would still experience a rise in global average temperature of 3°C by the end of the century. The recent Australian Academy of Science (AAS) report "The Risks to Australia of a 3°C Warmer World" describes in great detail our vulnerability to such a future, and the risks and costs that we would experience (Hoegh-Guldberg et al. 2021). In short, the report is an assessment of the devastating impacts we would suffer if we, and the rest of the world, continue on our present pathway.

The AAS report is a risk assessment based on peer-reviewed scientific literature. As the report authors state: “We adopted the precautionary principle: if a potentially damaging effect cannot be ruled out, it needs to be taken seriously.”

Assessing what Australia might experience at 3°C or more of warming is based on a synthesis of multiple lines of evidence – observations of what is already occurring at a 1.1°C global temperature rise, modelling future impacts, and assessing the evidence from historical and paleoclimate records. The report paints a vivid picture of what life might be like if we don’t achieve the Paris agreement targets.

- **Impacts on health and well-being:** The most serious threats to our health are becoming well known at a temperature rise of 1.1°C – bushfires, extreme heat, droughts, cyclones and storms, and torrential rains, flooding and hailstorms. Such events will become much more intense and more frequent in a 3°C world. A much hotter world will also exacerbate other, longer-term factors that can damage physical and mental health – such as ongoing decreases in rainfall, an increase in climate-sensitive infectious and vector-borne diseases, and the psychological impacts of economic hardships driven by a changing climate.

- **Australia’s cities and towns in a 3°C world:** We are one of the most urbanised countries in the world, and worsening climate change brings multiple threats to our cities and towns. A one-metre sea-level rise, possible by the end of the century, would put 160,000 to 250,000 properties at risk of increasing coastal flooding. The combination of rising sea levels and increasingly intense low-pressure systems and cyclones greatly increases the damage from storm surges, inundation and coastal erosion. Extreme heat, bushfires and severe storms put mounting pressure on urban infrastructure and dwellings, rendering many properties and businesses uninsurable.

- **Impacts on Australia's ecosystems:** At a rise of 1.1°C in global temperature, the Great Barrier Reef has already suffered three mass bleaching events in the last five years. The Reef would cease to exist in a 3°C world. Intensifying heat stress would destroy many other coastal and marine ecosystems, with significant loss of biodiversity. Many land ecosystems would be destroyed or changed beyond recognition as multiple climate-related stresses – extreme heatwaves, bushfires and drought – intensify further and become more frequent.

- **Costs to Australia's primary industries – agriculture, forestry, fisheries and food production:** The long-term drying trends in southwest and southeast Australia, punctuated by severe droughts, are already hammering our most important agricultural regions. In a 3°C world, escalating heat stress would have severe impacts on the welfare, production and reproduction of livestock. Primary producers would suffer reduced water availability, elevated heat stress and reduced water supplies, triggering declining health and economic well-being.

In summary, a 3°C world would have devastating consequences for Australia and the rest of the planet. There is much to be protected and saved in limiting warming to well below 2°C.

5.2 Tipping elements

Many future scenarios of global warming assume that the rise in atmospheric CO_2 concentration will be caused primarily by human emissions of greenhouse gases and that the climate responds in a predictable, linear way to the concentration of CO_2 and other greenhouse gases. The more CO_2 and other greenhouse gases we emit, the higher the Earth's temperature becomes.

However, complex systems almost by definition are not simple. A growing body of research warns that the Earth System contains 'tipping elements', where slowly increasing pressure can cause an element to cross a critical threshold, leading to sometimes abrupt, non-linear and often irreversible changes (Lenton et al. 2008; 2019; Schellnhuber et al. 2016). These 'wildcards' could push the global climate into dangerous territory, even if human greenhouse gas emissions are eventually reduced or eliminated (for example, Steffen et al. 2018; Lenton et al. 2019).

There's a growing body of evidence that the Earth System contains 'tipping elements' which, if crossed, will lead to sometimes abrupt and often irreversible changes.

Tipping elements in the Earth System come in three basic forms (Figure 19):

- **Ice:** This includes the large polar ice sheets on Greenland and Antarctica, as well as the floating sea ice in the Arctic Ocean and Siberian permafrost. For example, the threshold for melting the Greenland ice sheet could lie at a particular surface elevation. As an ice sheet melts, its elevation lowers, exposing it to ever-warmer air, driving accelerating melt rates. Beyond the critical elevation, melting becomes irreversible. For the Antarctic ice sheets, basal melting from warming seas is more important as many of the outlet glaciers are grounded under sea level. Warming of the deep ocean could release a massive amount of methane, stored beneath the ocean floor as methane clathrates.[12]

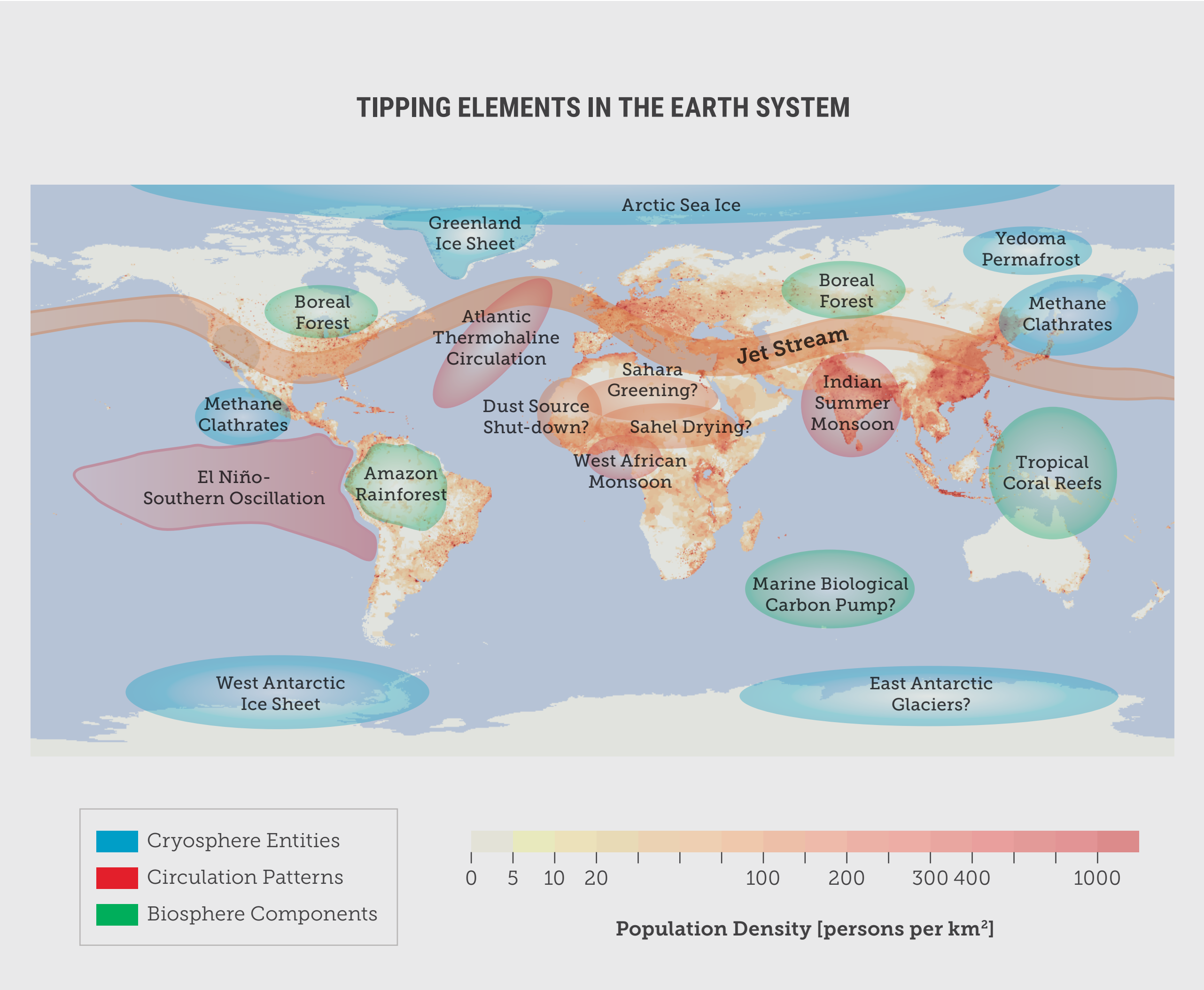
- **Biomes (large ecosystems):** These include large forest biomes, such as the Amazon rainforest and the vast boreal forests that stretch across northern Canada, Scandinavia and Siberia. The Amazon faces a double whammy. Both deforestation and changes in Atlantic Ocean circulation are reducing rainfall over the basin, increasing the risk of fires that could become frequent and severe enough to convert the forest into a tropical woodland or savanna. Coral reefs, such as Australia's Great Barrier Reef, are a good example of a marine ecosystem with a well-defined thermal threshold; that is, sensitivity of ecosystems to changes in temperature rather than rainfall.

12 Clathrates are a substance in which molecules of one type (in this case methane) are trapped by a lattice formed by other molecules.

- **Circulation patterns:** these occur in the atmosphere, such as the northern hemisphere jet stream, in the ocean such as the Atlantic thermohaline circulation,[13] and coupled ocean-atmosphere systems such as the El Niño–Southern Oscillation. Significant changes in these circulation systems can have global, hemispheric or regional consequences for the climate system, triggering changes in rainfall patterns, storm tracks, and extreme heat events.

Many tipping elements in the Earth System are sensitive to changes in temperature. Predicting precisely when a biome or ice sheet will cross a threshold is very difficult, so most analyses of when a tipping point might be crossed are based on risk assessments that integrate observations and modelling studies. Given the serious impacts of tipping large ice sheets such as that on Greenland or major biomes like the Amazon rainforest, even low probabilities of tipping are of serious concern (Lenton et al. 2008, 2019).

Figure 19: Tipping elements in the Earth System. **Source:** Adapted from Richardson et al. 2011.

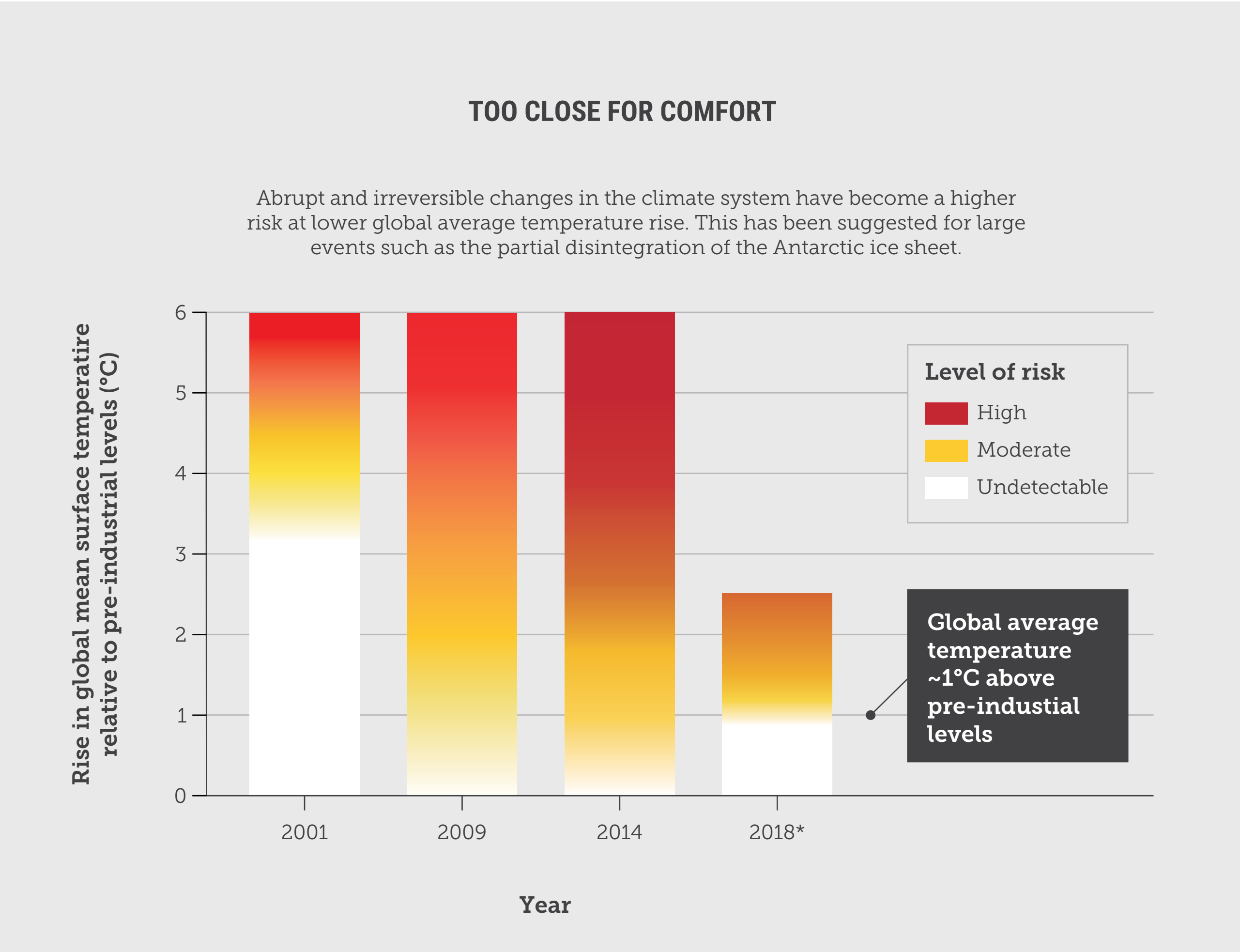


13 Thermohaline circulations are those driven by differences in water density. These differences depend on temperature (thermo) and salinity (haline). Changes in salinity result from the formation and melting of sea ice, precipitation and other factors.

The IPCC assessments have included estimates of the risk of breaching tipping points in the Earth System at increasing levels of temperature rise (Figure 20). These assessments have shown that risks of triggering tipping elements in the Earth System occur at lower temperatures than previously thought. When the IPCC first introduced the idea of tipping points over two decades ago, these ‘large-scale discontinuities’ were only considered likely if global warming exceeded 5°C. As shown in Figure 20, the most recent risk assessment shows that at the current 1.1°C increase in global average, we have already entered a region of moderate risk of irreversible changes (IPCC 2018, 2019).

Consistent with the IPCC (2018) assessment of tipping point risks, observations show that many tipping elements have already begun to destabilise in response to today’s rise in temperatures and changing rainfall (Figure 21). For example, ice loss from large ice sheets on both Greenland and Antarctica is accelerating, with the West Antarctic ice sheet projected to lose enough ice with only 2°C of global warming to raise global sea level by 2.5 metres (Garbe et al. 2020). In addition to destabilising ice sheets, the Amazon rainforest is experiencing more frequent droughts and fires, Siberian permafrost is beginning to thaw, and the Atlantic circulation has been slowing since the 1950s (Lenton et al. 2019). While it is unlikely than any thresholds have been crossed yet, it is worrying that so many tipping processes have been activated.

Figure 20: The estimated risk of activating tipping elements has increased as scientific understanding has developed and shows higher likelihoods at lower temperature rises than before. **Source:** Lenton et al. 2019, based on IPCC assessments.

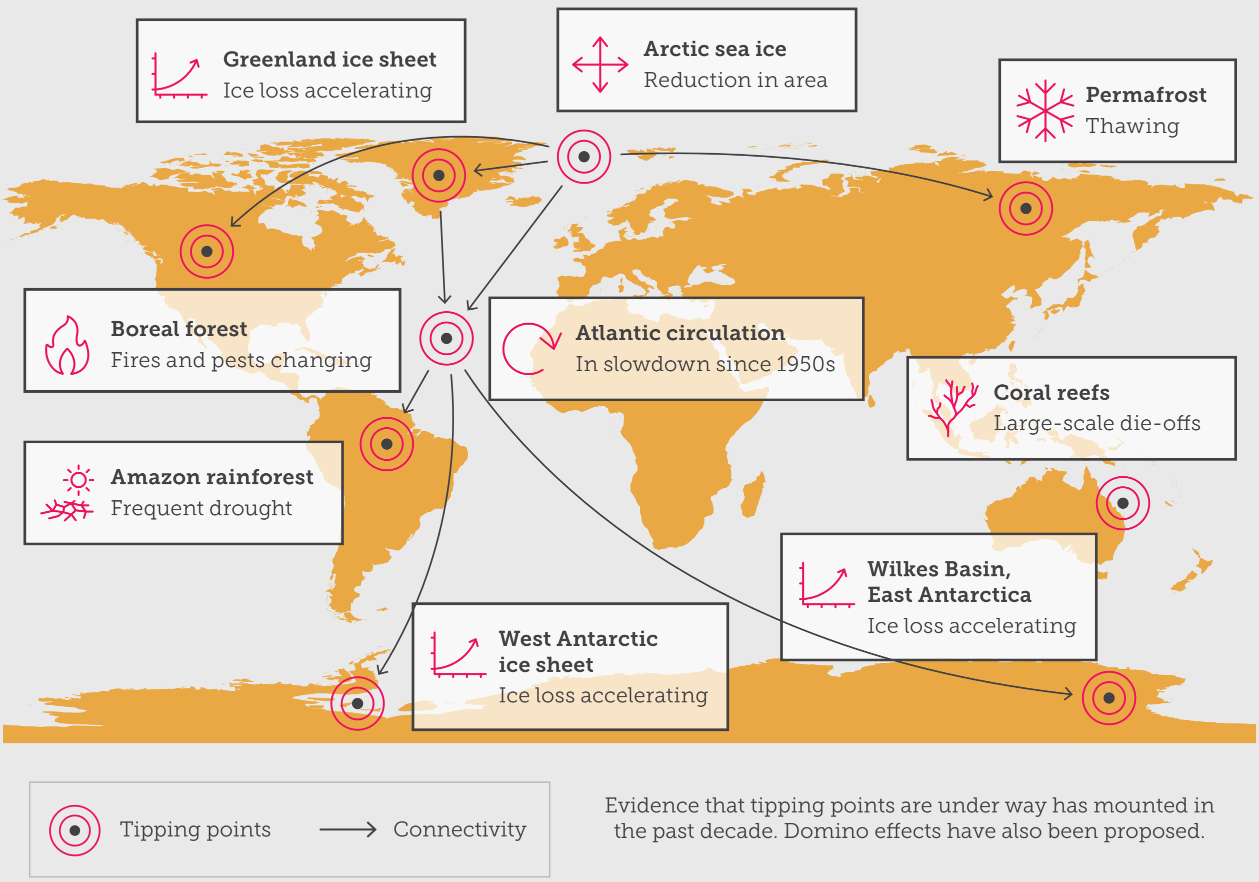


*The 2018 IPCC special report on Global Warming of 1.5°C is focused on the temperature range up to 2.5°C.

BOX 4: TIPPING CASCADES

It is very likely that tipping elements do not act in isolation but rather tipping one or two of the elements could contribute to destabilising others, increasing the likelihood that they also will cross a threshold. The overall effect would be to form a 'tipping cascade'. Like a row of tumbling dominoes triggered by pushing over the first domino or two, a tipping cascade could ultimately trigger a wide range of individual tipping elements. If such a tipping cascade is generated, it would essentially take the future pathway of climate change beyond human control. We could rapidly reduce our greenhouse gas emissions but the Earth System would continue to warm until it reaches a new stable state, much hotter than the climate conditions of the past several thousand years during which we have developed the complex human societies of today (Lenton et al. 2019; Steffen et al. 2018).

RAISING THE ALARM



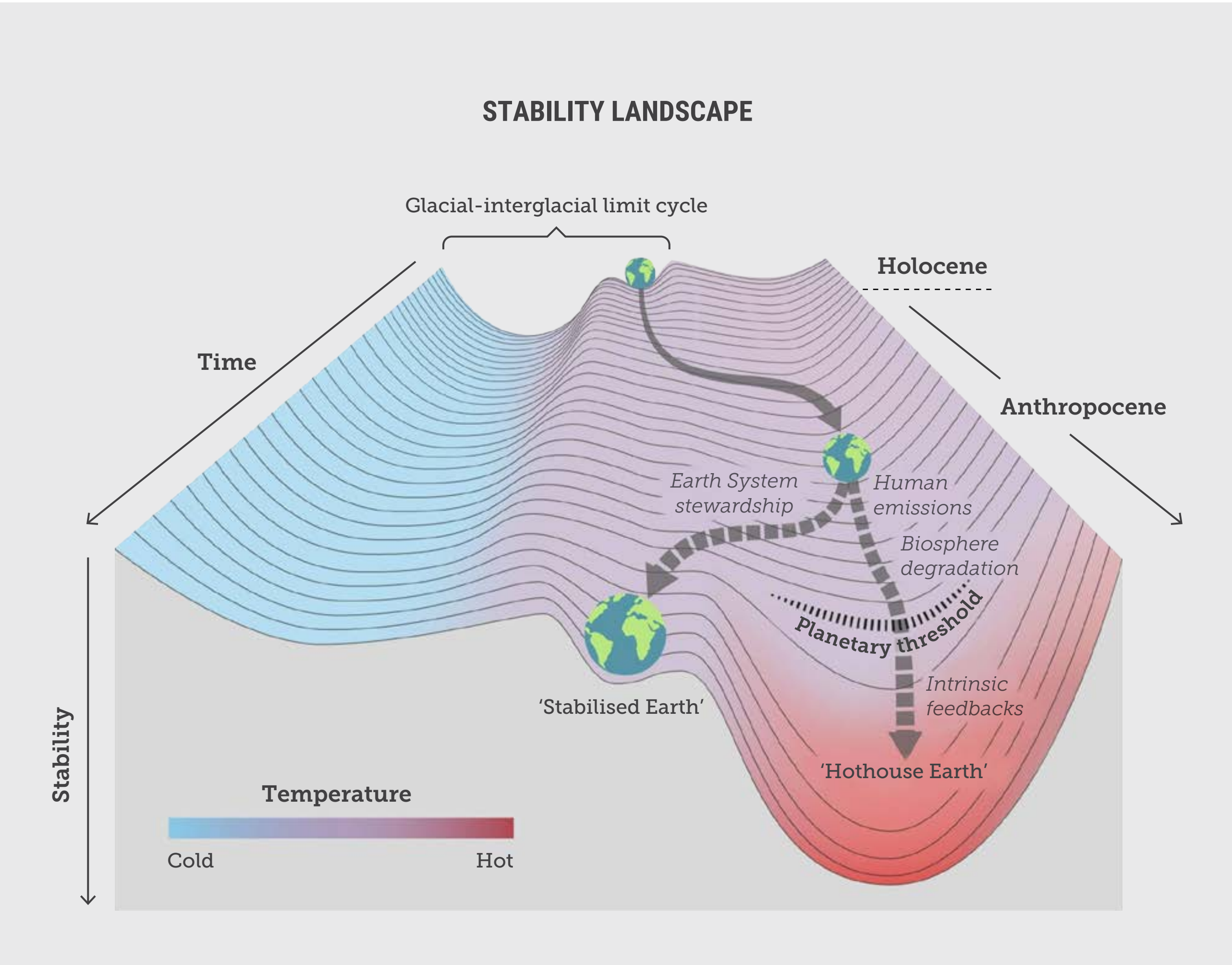
Evidence that tipping points are under way has mounted in the past decade. Domino effects have also been proposed.

Figure 21: The connections between individual tipping elements that may lead to a possible tipping cascade. **Source:** Lenton et al. 2019.

As shown in Figure 20, the risk of activating tipping elements increases as the global average temperature rises. While a global tipping cascade (Box 4) is unlikely to be triggered at warming of 1.5°C, the risk rises as temperature increases towards 2°C and beyond. While we still have a chance of avoiding a global tipping cascade at well below 2°C, it is likely that the risk rises sharply beyond 2°C above pre-industrial conditions. The projected temperature rise of 2.7°C to 3.1°C that would result from current policies (Climate Action Tracker 2020) would push the climate into dangerous territory, with many tipping elements likely to be transgressed and a much higher risk of triggering a global tipping cascade.

This risk is presented in the form of a 'stability landscape' (Figure 22), a simple visual representation of a more detailed complex systems analysis (Steffen et al. 2018). The global tipping cascade is shown as a 'planetary threshold', the cliff in the stability

Figure 22: A 'stability landscape' showing two potential pathways for the Earth System. Beyond the 'planetary threshold', a potential tipping cascade could take the trajectory of the system beyond human control and irreversibly towards 'Hothouse Earth'. **Source:** Steffen et al. 2018.



landscape. Driving the Earth System onto a pathway that takes it over the cliff means that we are irreversibly committed to 'Hothouse Earth', equivalent to the IPCC high emissions (RCP8.5) scenario. The other pathway, equivalent to meeting the *Paris Agreement* long-term temperature goal, leads to 'Stablized Earth'. Figure 22 shows the Earth System in 2020, poised at the fork in the road. We are at a critical point in the climate change challenge.

In summary, the analysis outlined visually in Figure 22 supports the case for a climate emergency. As emphasised by Lenton et al. (2019):

> *"If damaging tipping cascades can occur and a global tipping point cannot be ruled out, then this is an existential threat to civilization. No amount of economic cost-benefit analysis is going to help us. We need to change our approach to the climate problem".*

The risk of activating tipping elements, and in turn a global tipping cascade, rises sharply when warming goes beyond 2°C.

6. The pathway we choose

Ten years ago, nearly to the month, the forerunner of the Climate Council (the Climate Commission) published its first major report "The Critical Decade: Climate science, risks and responses". This report outlined the emerging scientific understanding of climate change, and offered potential future pathways towards stabilising the climate.

Back then, a sense of urgency was missing. Tipping points were hypothetical and a long way off. Climate impacts were worsening but still manageable. In fact, had global greenhouse gas emissions levelled in 2011, the world then could have slowly and steadily reduced emissions (peaking at a maximum rate of 3.7% per year), reaching net zero emissions sometime in the second half of the century and keeping temperature rise well below 2°C.

Now, just a decade later, lack of effective action globally, typified by the 'climate wars' here in Australia, has deepened the hole we're in. It is harder to get ourselves out, and if we keep digging in, then our future is ominous.

The risks of climate change to Australia are obvious and growing. The horrific damage of the 2019-2020 Black Summer bushfires is still fresh in our minds. In March 2020, the Great Barrier Reef suffered its third mass bleaching event in just five years, causing catastrophic, irreversible damage (Hughes et al. 2018a, b; 2019; JCU 2020). Extreme heat is on the rise and rainfall patterns are changing, with the major agricultural zones in the southwest and southeast of the continent experiencing long-term, cool season drying trends (Grose et al. 2020).

Globally, the ocean is warming, the Greenland and West Antarctic ice sheets are melting (IPCC 2019), and sea-level rise is accelerating. Siberia is experiencing extraordinarily hot conditions (NOAA 2020), increasing the melting of permafrost. The most vulnerable people are already suffering increased coastal flooding, exacerbated by tropical cyclones that are increasing in intensity (Kirezci et al. 2020). The climate system is sending us warning after warning. We still have the choice to act, but time is running out and that choice could quickly vanish.

Although it is now impossible to limit temperature rise to 1.5°C without significant overshoot and subsequent drawdown, we can still hold global warming well below 2°C, and must do everything in our power to do so.

At the same time that climate change has accelerated, the solutions available to meet the formidable challenge of stabilising the climate have grown at an astounding rate. For example, it has never been cheaper or easier to transform our energy system and electrify sectors like transport. The secondary benefits are many and highly desirable – such as quieter cities, cheaper power, less smog and better health outcomes.

A brighter future, built on a goal of net zero emissions by 2035, is achievable but requires urgency, determination and a whole-of-society effort. Reducing emissions by 75% in just one decade will no doubt be disruptive in many ways. Social support systems will need to be built to help those whose jobs, careers, and skills will disappear with the old technologies. Old industries and powerful interest groups will be left behind as investment rapidly swings into the new economy. Some regions will have to transition to new forms of economic activity. There will be hard decisions, there will be disruptions that may be painful, and there must be step changes – at a war-time scale – in our response to this challenge. Managing such a deep and rapid transformation will require considerable support from governments and other bodies, given the structural adjustments and societal turbulence that will accompany such widespread and rapid change. But the long-term benefits far outweigh the short-term challenges that we might face.

The target for Australia of reducing emissions by 75% below 2005 levels by 2030 also raises obvious questions of feasibility. But societies have faced similarly large, time-constrained challenges in the past and have succeeded. The most well-known example was the very deep, lightning-quick and highly disruptive transformation of the Allied countries and their economies to defeat the Axis powers in World War II. Another example was the United States' campaign in the 1960s to land people on the moon in less than a decade, starting from a much more primitive technological base than we have at our disposal today. Both of these examples led to widespread economic, social, health and security benefits in the decades that followed.

A brighter future, built on a goal of net zero emissions by 2035, is achievable through a determined, whole-of-society effort.

The effort in Australia to help limit warming to well below 2°C has to include several key elements:

- Banning any new fossil fuel developments, including gas.
- Phasing out all existing fossil fuels and replacing them with other energy sources, built around renewable electricity.
- Building a stronger, more diverse economy, creating more jobs and spreading benefits to regional centres and communities.
- Stepping up as a global exporter of zero emissions energy, technology and expertise.
- Protecting Australia's unique ecosystems by building resilience to future climate threats.

With a renewables-led economic recovery, it is possible to rapidly scale-up our actions and trigger a virtuous cycle of accelerating decarbonisation that cuts our greenhouse gas emissions deeply by 2030 and achieves net zero emissions by 2035. It starts with stepping up our efforts now, recognising the urgency of the challenge we face, and getting ourselves onto the right trajectory.

Renewable energy is already cheaper than fossil fuels, has the potential to employ more people, creates jobs across regional Australia, and can be expanded rapidly. The multiple benefits of renewables can extend beyond the energy sector itself by using renewable energy to power transport, heating and cooling, and other sectors of the economy (Climate Council 2020b, 2020c, 2020d).

A renewables-led economic recovery could ultimately transform Australia into a clean energy superpower. With our enormous potential for renewable energy and our relative proximity to large, densely populated countries to our north in Asia, Australia has the opportunity to become a global exporter of zero emissions energy. Our renewable resources could underpin a large export industry supplying zero emissions energy, products, minerals and services to other countries.

However, while many other countries are moving rapidly in this direction, the Australian Federal Government stands almost alone and stationary. It refuses to strengthen the small, faltering steps it announced five years ago.

Why? What is holding us back? The benefits of a renewables-led Australian economy and society are immense: more vibrant regional communities and sustainable capital cities, cleaner and more reliable transport systems, ongoing job creation, a more diverse and resilient economy and the regeneration and protection of our unique ecosystems.

Acting in Australia's interests means acting swiftly and boldly to tackle the climate challenge. The pathway we choose now will either put us on track for a much brighter future for our children, or lock in escalating risks of dangerous climate change. The decision is ours to make. Failure is not an option.

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Appendix A: Uncertainties in the Carbon Budget

1. **Non-CO_2 greenhouse gases and aerosols.** The IPCC SR1.5 estimate for this uncertainty is about -400 to +200 Gt CO_2. We estimate this uncertainty would reduce the remaining budget by a relatively modest 90 Gt CO_2. Our rationale is that: (i) both CH_4 and N_2O emissions are rising, with the rate of CH_4 emissions increasing over the past decade after a period of very little or no growth (Jackson et al. 2020) and emissions of N_2O increasing at a rate of about 2% per decade (Tian et al. 2020); (ii) a significant fraction of both CH_4 and N_2O emissions come from the agriculture sector, and are considered more difficult to reduce than CO_2 emissions; and (iii) global aerosol emissions could decrease in future, as they have in China over the past decade or so, as countries take measures to reduce local air pollution. The net effect of these assumptions is that the CO_2 budget will need to be reduced further to compensate for both of these effects.

2. **Carbon cycle feedbacks.** We include here the IPCC SR1.5 estimate of an approximate 100 Gt CO_2 reduction in the budget due to emissions from permafrost melting (IPCC 2018). We also include estimates of CO_2 emissions from the Amazon rainforest, due to a combination of human-driven deforestation and dieback from a drying climate, and from the boreal forest, due to changes in climate-driven disturbance regimes. These estimates, which are based on an assessment of both observations under current levels of climate forcing as well as model-based future scenarios (Steffen et al. 2018, and references therein), add another 145 Gt CO_2 to the overall estimate of feedbacks. These carbon cycle feedbacks are applicable for a temperature target at 2100 (IPCC 2018; Steffen et al. 2018) so would be relevant to a trajectory that stabilised the temperature at 1.5°C around mid-century and maintained that average temperature to the end of the century.

The assumptions on which the budget in in Table 1 of the main report is based are realistic given the difficulty in reducing non-CO_2 gas emissions and the observation that many Earth System feedback processes are already being activated by a 1.1°C forcing (Lenton et al. 2019). However, we can create a more 'optimistic' budget by reducing emissions of methane, nitrous oxide and other non-CO_2 gases at the same rate as we reduce CO_2 emissions. This would increase our budget by 90 Gt CO_2. We could also include permafrost melting, which the IPCC estimates at about 100 Gt CO_2 for a 1.5°C forcing, as the only feedback. This would increase the budget by an additional 145 Gt CO_2. The budget would then become 110 + 235 Gt CO_2 = 345 Gt CO_2. This budget would last about eight years at current rates of emission, or about 16 years with a linear rate of emissions reductions (Box 2). This budget corresponds to a 50% reduction by 2028 and net zero by 2036. A similar, more generous, budget could be constructed by adopting the non-CO_2 gas and carbon feedback assumptions of Table 1 but assuming only a 50% probability of limiting warming to 1.5°C (IPCC 2018).

ESTIMATION OF CARBON FEEDBACKS

Estimation of carbon cycle feedbacks were taken from the IPCC SR1.5 report (for permafrost) and from Steffen et al. (2018; Supporting Information) for other feedbacks. Feedback strengths were estimated from a synthesis of the relevant literature, and generally included both observations and modelling studies. Feedbacks were estimated for an 83-year period from 2017 (the time of the analysis) to 2100 with a temperature forcing based on a stabilisation by 2100 at a 2°C temperature rise. Although Steffen et al. (2018) estimated a wide range of feedbacks, we include here only carbon emissions from Amazon and boreal forest dieback in addition to the melting of permafrost. The relevant estimates from Steffen et al. (2018) are shown below in Table 3, and scaled linearly to a 1.5°C forcing in the second column:

Table 3:

	2°C forcing	1.5°C forcing
Permafrost:	45 (20-80) Gt C	34 Gt C
Amazon forest dieback:	25 (15-55) Gt C	19 Gt C
Boreal forest dieback:	30 (10-40) Gt C	22 Gt C

Note that the Steffen et al. estimate of permafrost feedback strength (34 Gt C) is similar to the estimate from the IPCC SR1.5 report (100 Gt CO_2, or 27 Gt C). Here we have used the IPCC estimate, coupled with the estimates of Amazon and boreal dieback from Steffen et al. (2018), to give an overall feedback strength of 70 Gt C, rounded to the nearest 5 Gt C.

There are considerable uncertainties around estimates of feedback strengths. The Steffen et al. (2018) estimates would give, for a 1.5°C forcing, a feedback of about 35 Gt C for the low range estimate and an estimate of 130 Gt C for the high range, the latter eliminating the remaining budget for limiting warming to 1.5°C (Table 1 of main report).

The full feedback analysis of Steffen et al. (2018) is available from https://www.pnas.org/content/115/33/8252

Appendix B: Open letter from Australian climate scientists to former Chief Scientist Dr Alan Finkel

24 August 2020

Dr Finkel,

We are writing to you as Chief Scientist with our concerns about your strategy for dealing with climate change, and to offer any scientific advice that you might find useful on climate change issues.

With the Black Summer bushfires and yet another mass bleaching of the Great Barrier Reef fresh in our minds, meeting the climate change challenge is more urgent and daunting than ever. The Paris Climate Agreement, to which Australia is a signatory, provides the global framework for addressing this challenge. It calls for nations to take action to keep global temperature rise to 'well below 2°C and to pursue efforts to limit the temperature increase to 1.5°C'.

In your February speech to the National Press Club entitled "The Orderly Transition to the Electric Planet",[1] and in other publications and presentations, you have emphasised the importance of transitioning to renewables such as solar and wind, and that they should become the backbone of a 21st century clean economy. We strongly support this approach, and agree that renewables firmed by batteries and pumped hydro comprise a very effective approach to tackling the emissions reduction challenge.

Our concern, however, relates to the scale and speed of the decarbonisation challenge required to meet the *Paris Agreement*, and, in particular, your support for the use of gas as a transition fuel over 'many decades'. Unfortunately, that approach is not consistent with a safe climate nor, more specifically, with the *Paris Agreement*. There is no role for an expansion of the gas industry.

There are multiple lines of evidence to support our position on gas:

- We are already committed to a temperature rise of 1.3°C or 1.4°C from past greenhouse gas emissions, primarily from the combustion of coal, oil and gas.[2,3] At this point it would take a global social, political and technological miracle to keep the world under 1.5°C.[4]

- Exceeding even 1.5°C will have escalating impacts on Australia.[5]

- The combustion of natural gas is now the fastest growing source of carbon dioxide to the atmosphere, the most important greenhouse gas driving climate change.[6,7]

- Global methane emissions from fossil fuel sources and from agriculture are accelerating.[8,9] On a decadal timeframe, methane is a far more potent greenhouse gas than carbon dioxide. In Australia, the rapid rise in methane emissions is due to the expansion of the natural gas industry.[10] The rate of methane leakage from the full gas economy, from exploration through to end use, has far exceeded earlier estimates.[11]

- Existing and planned fossil fuel infrastructure is more than sufficient to push the world past 2°C, pushing even the upper bounds of the *Paris Agreement*'s temperature goals well out of reach.[12]

- To meet the upper Paris goal ('well below 2°C'), we must achieve net zero emissions by 2040-2050. This requires a rapid phase-out of existing fossil fuel infrastructure, leaving no room for expansion of the gas industry.

- While in principle CCS (Carbon Capture and Storage) could extend the life of fossil fuels - for example, for use in the production of hydrogen - CCS technology is still far from being technologically and economically viable. The renewable energy-based alternatives are already technologically ready, less expensive, and more widespread, capable of delivering economic and employment benefits across regional and rural Australia.

The undeniable conclusion from this analysis is that the time has passed for any new fossil fuel infrastructure, including the proposed expansion of the gas industry in Australia. All types of fossil fuels, including gas, contribute to climate change and all must be phased out as quickly as possible to meet the *Paris Agreement* targets, helping to keep Australians safe now and into the future.[5]

We reiterate that we very much appreciate your efforts and leadership in facilitating the rapid expansion of the renewable energy sector. This is a major step forward. But we must now make urgent progress towards a prosperous net zero emissions economy by 2040- 2050.

As always, we stand ready to provide advice on the science of climate change and to support your efforts to expand and accelerate the actions needed to do our part in the global effort to meet the goals of the *Paris Agreement*.

Yours sincerely,

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Appendix C: Australia and the global emissions reduction task

Australia should aim to achieve net zero emissions by 2035, and reduce emissions by 75% below 2005 levels by 2030.

The physical science shows us that to limit warming to well below 2°C, global emissions will need to be at least halved over the coming decade and reach net zero by around 2040.

The *Paris Agreement* commits all countries to doing their very best towards achieving this long-term temperature goal, and requires countries' Nationally Determined Contributions (NDCs), including their emissions reduction targets, to reflect their "highest possible ambition" (Article 4.1). The Agreement also requires these targets to reflect countries' "common but differentiated responsibilities and respective capabilities, in light of different national circumstances", often abbreviated as CBDR.

This principle of CBDR is fundamental to global cooperation on climate change and was enshrined in the United Nations Framework Convention on Climate Change (UNFCCC), upon which the *Paris Agreement* is built. It recognizes that while all countries have a crucial role in tackling climate change, they have varying levels of responsibility for its causes and, perhaps more importantly, differing capacities and opportunities when it comes to reducing emissions.

A country's 'cumulative emissions' (that is, the total amount it has emitted since a given date), its current level of emissions per person, its overall economic strength, and various elements of its 'national circumstances', including levels of poverty, the makeup of its economy, and its potential to generate renewable energy, are among the many factors that could be considered relevant in determining a country's 'fair share' of the global emissions reduction task, including how soon it should be expected to reach net zero emissions, and how much it should aim to cut emissions over the coming decade, noting again that all country's commitments should reflect their "highest possible ambition".

For example, a country that has built up considerable wealth off the back of fossil fuel energy bears both greater responsibility for the greenhouse gas emissions that are driving climate change, and has likely reached a level of development and economic strength that mean it is well placed to take strong action on climate solutions. Such a country can and must cut emissions faster than a 'less developed country', which will typically be responsible for a far lower proportion of the emissions already in the atmosphere, continue to have a much lower level of emissions per person, and may have more limited options for immediate and deep cuts to emissions.

While many different formulas and methodologies have been proposed, there is no universally accepted way for translating the global emissions reduction task into targets for each country, in line with the principles of the UNFCCC and *Paris Agreement*, as there are a multitude of ways in which the many relevant factors may be interpreted and weighted. For example, when it comes to a country's cumulative emissions – in other words, their historical contribution to the problem of climate change – some advocates argue that these should be counted since the beginning of the industrial revolution, as this is the point at which global emissions began to rise, and is the period to which we reference the resulting global average temperature rise. Others argue that it is only reasonable to count cumulative emissions since the time at which the world became widely aware of the dangers of greenhouse gas emissions, typically taken to be around 1990, in which the International Panel on Climate Change (IPCC)'s First Assessment Report was published, followed shortly by the creation of the UNFCCC. Others have argued that a country's current national circumstances are a much more important consideration than its historic responsibility. Typically, countries have interpreted the UNFCCC's 'equity principles' in such a way as to justify making less effort rather than more, which has contributed to today's combined commitments being very far short of the scale and pace of global action required (UNFCCC 2021).

However, what becomes abundantly clear for Australia is that no matter how we choose to interpret and weight these different factors, Australia should be expected to reduce its emissions at a significantly faster rate than the required global average, and achieve net zero emissions sooner than most of the rest of the world. Through our cumulative emissions we bear a disproportionate responsibility for climate change. Economically, we are one of the wealthiest nations on Earth. Moreover, Australia is blessed with some of the world's best potential for renewable energy and other climate solutions (see Chapter 6) – a key consideration when it comes to our national circumstances and the ease with which we can reduce emissions compared to many other countries. Therefore, whether on grounds of historic responsibility, economic capability, or national circumstances, Australia has the responsibility and capacity to act ahead of the rest of the world.

In 2014, Australia's Climate Change Authority, after a detailed assessment of factors relevant to Australia's emissions reduction targets, proposed that Australia should reduce its emissions by between 45-65% below 2005 levels by 2030: a significantly more ambitious target than the 26-28% below 2005 levels by 2030 that the Australian Government ultimately took to Paris[14] (Climate Change Authority 2014). As part of its method for determining Australia's fair share of the global emissions reduction task, the Climate Change Authority used a modified version of a formula known as 'contraction and convergence' – by which, once the amount by which global emissions are required to contract has been determined, every country's emissions per person converge to meet an equal level of emissions per person required to remain within that budget.

In 2021, a group of eminent Australian climate scientists took the same 'modified contraction and convergence' methodology used by the Climate Change Authority in 2014 to provide updated advice on what Australia's emissions reduction targets should be (Climate Targets Panel 2021). This advice took account of many important changes since 2014: the fact that emissions have continued to rise, both in Australia and worldwide; advances in our understanding

14 In its original advice, the target was expressed against a 2000 baseline. However, since the Australian Government decided to use a 2005 baseline for its first Nationally Determined Contribution to the Paris Agreement, the 2014 advice from the Climate Change Authority is today usually expressed against a 2005 baseline. 45-65% below 2005 levels is roughly equivalent to the Climate Change Authority's original figure of 40-60% below 2000 levels.

of the available global carbon budget; and the implications of the *Paris Agreement*, which was finalised after the Climate Change Authority issued its 2014 advice. Using the modified contraction and convergence methodology, Australia was allocated a fairly generous 0.97% of the remaining global carbon budget. Australia accounts for around 0.3% of the global population, making Australia's carbon budget allocation under this methodology about three times higher than if the remaining global carbon budget were allocated on an equal per capita basis.

The Panel determined that to be consistent with limiting warming to well below 2°C, or the upper bound of the *Paris Agreement*'s long-term temperature goal, Australia's 2030 emissions target must be 50% below 2005, a 2035 target would need to be 67% below 2005 levels, and net zero emissions would need to be reached by 2045. This target is based on a carbon budget that does not include carbon cycle feedbacks, and furthermore allows Australia a generous 0.97% of the global budget. Taking these factors into account would tighten the Panel's target, bringing it more in line with the Climate Council's recommended target of net zero emissions by 2035, with a 75% emission reduction by 2030.

Importantly, multiple research bodies including ClimateWorks Australia have demonstrated that net zero by 2035 is possible for Australia, meaning it falls within the scope of the "highest possible ambition" that countries are required to bring to the table (ClimateWorks Australia 2020).

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