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The ARC Centre of Excellence
for Climate Extremes

30th June 2023

Consultation Hub
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Submission to the Climate Change Authority Issues Paper: Setting, measuring and achieving Australia's emissions reduction targets.

The ARC Centre of Excellence for Climate Extremes welcomes the opportunity to make a submission to the Climate Change Authority Issues Paper: Setting, measuring and achieving Australia's emissions reduction targets.

As Australia's leading climate science centre, we recognise the risks of climate change for all Australians and hold valuable perspectives informed by the most recent research in climate science. Australian communities are exposed to severe impacts from weather and climate events with risks growing through time if emissions are not reduced. The effects are felt across society, from food and water to fuel and finance, leading to damage of Australia's social, environmental and economic systems. Our centre's work improves the national capacity to understand the processes underlying climate extremes and how these may change and affect us into the future.

It has been clear since the signing of the United Nations Framework Convention on Climate Change in 1992, that continued greenhouse gas emissions will cause dangerous changes to the climate system. Some of these changes have already been observed, however it is not too late to deliver deep cuts in emissions to limit climate impacts and keep the goals of the Paris Agreement within reach.

We thank the Climate Change Authority for the opportunity to make a submission on this topic and offer our expertise on Australia's climate targets and the impacts of climate extremes. We are happy to provide further information on any matters arising from this submission.

Our submission provides responses to a select group of questions where we have expertise and experience: 1,2,4,5,9,11 and 19.

Yours sincerely,

Professor Andrew Pitman, AO, FAA
Centre Director
ARC Centre of Excellence for Climate Extremes

Introduction

The United Nations' Sixth Intergovernmental Panel on Climate Change (IPCC) report[1] states climate change is causing greater impacts than anticipated, and these impacts are emerging at lower amounts of warming than expected, declaring,

'..the next few years are critical[2].'

The report underlines the urgent need for emissions reductions to limit warming to well below 2°C above pre-industrial levels and pursue efforts to limit warming to 1.5°C to avoid dangerous climate change, as stated in the Paris Agreement[3]. Future changes to Australia's climate depend on the cumulative total of greenhouse gases emitted over time. The more we emit now, the worse climate change will be in the future. With the impacts from climate extremes likely to increase with the warming that is already locked in, action towards future prevention is a national responsibility. In short, every additional fraction of a degree of warming increases the risk of extreme weather events.

Climate and weather extremes are affecting many facets of Australian society including infrastructure, human health, soil and water, agriculture, energy security, financial security and our natural environment, posing significant risks to the Australian and global economy. For example, research carried out by the ARC Centre of Excellence for Climate Extremes (the Centre) outlines projected changes in droughts are stronger in most regions under high emissions scenarios, with drought risk mitigated by reducing greenhouse gas emissions[4].

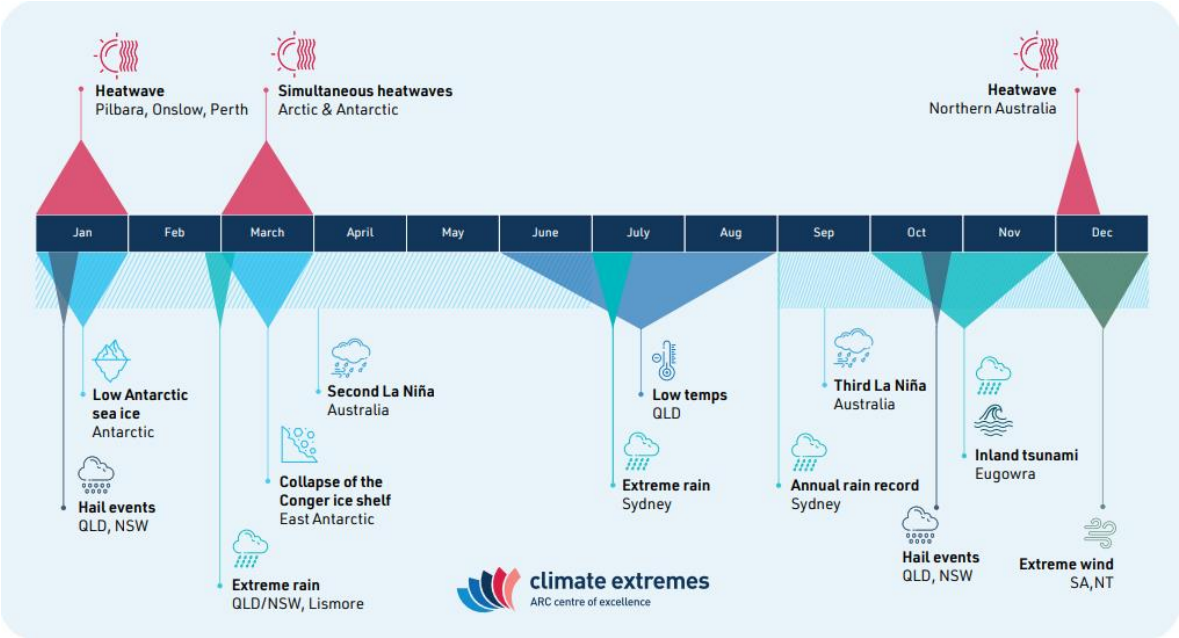


Figure 1: A year of climate extremes, 2022.

Australia experienced a year of record-breaking extreme events in 2022 (Figure 1) with extreme rain and flooding overshadowing all other events. There was persistent heavy rainfall breaking multiple

[1] IPCC, 2021, Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, https://www.ipcc.ch/report/ar6/wg1/chapter/summary-for-policymakers/

[2] IPCC, 2022, Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, https://www.ipcc.ch/report/sixth-assessment-report-working-group-3/

[3] United Nations Framework Convention on Climate Change. (2015). Paris Agreement. https://unfccc.int/sites/default/files/english_paris_agreement.pdf

[4] Ukkola et al., 2020, Robust Future Changes in Meteorological Drought in CMIP6 Projections Despite Uncertainty in Precipitation, Geophysical Research Letters, https://doi.org/10.1029/2020GL087820

daily, monthly, and yearly flood and rainfall records, with second and third consecutive La Niña events dominating weather and climate. While La Niña events typically bring more rainfall to Australia and cooler global average temperatures, climate change contributed to 2022 being the warmest La Niña year on record globally[5]. Australia also equalled its highest temperature ever in Western Australia. As an El Nino event and the prospect of associated increased temperatures and heatwaves are currently forecast, Australia is very likely to see more record high temperature extremes in the next few years.

Climate impacts due to anthropogenic warming

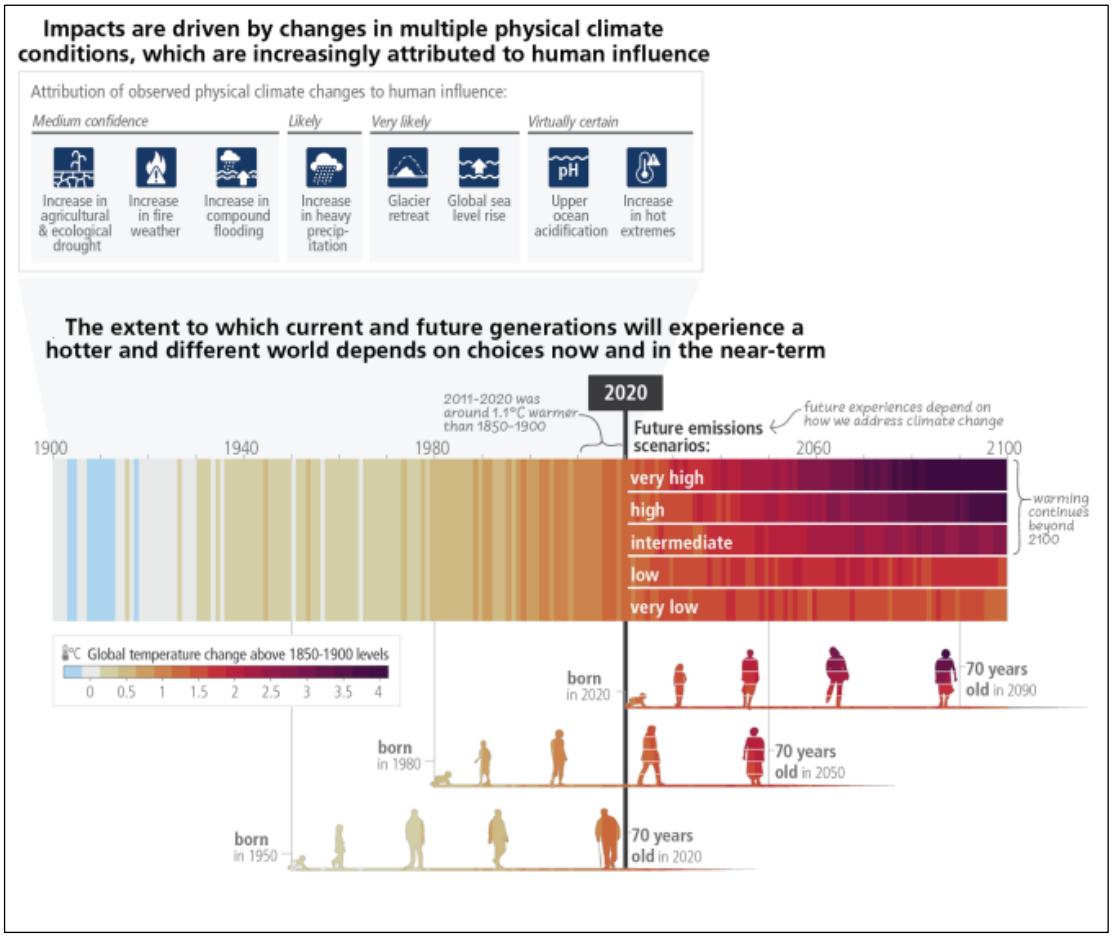


Figure 2: Adverse impacts from human-caused climate change will continue to intensify. Source: IPCC.

The IPCC Synthesis report[6] has stated that there have already been widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere which has led to widespread adverse impacts and related loss and damage to nature and people (Figure 2).

Attribution is the process where the causes of detected changes in the climate are determined. These causes may be natural (e.g., changes in the solar cycle, volcanic eruptions, La Niña) or human (e.g., emissions of greenhouse gases, deforestation, aerosols).

To illustrate the link between anthropogenic climate change and changes in our climate, we present 5 studies from Australia and across the globe.

[5] RealClimate, 2022, 2022 updates to the temperature records, January 2023 | RealClimate
[6] IPCC, 2023, AR6 Synthesis Report: Summary for Policymakers Headline Statements, https://www.ipcc.ch/report/ar6/syr/resources/spm-headline-statements/

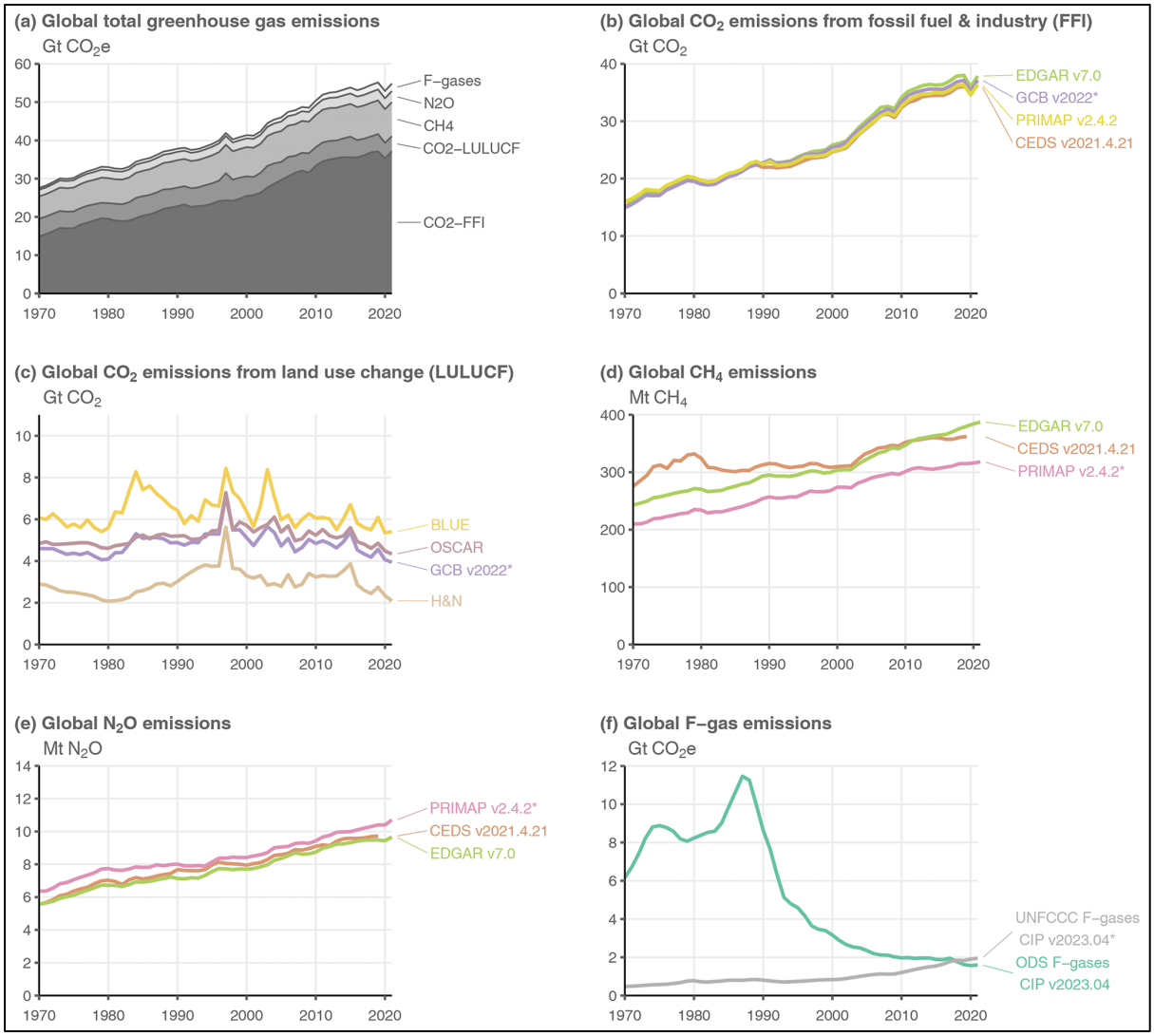
1. The number of new hot (high-maximum and high-minimum temperatures) temperature records increased dramatically in recent decades, while the number of cold records decreased. Increased hot record breaking occurs only in model experiments with anthropogenic forcings[7].
2. Local extreme temperatures can increase at a significantly higher rate than global average temperature under warming of 1.5°C and 2°C [8].
3. The overall intensity of the 2017/18 Tasman Sea marine heatwave was virtually impossible without anthropogenic forcing[9].
4. Global average marine heatwave frequency and duration increased by 34% and 17%, respectively, resulting in a 54% increase in annual marine heatwave days globally. Importantly, these trends can largely be explained by increases in mean ocean temperatures, suggesting that we can expect further increases in marine heatwave days under continued global warming[10].
5. Heatwaves in Australia have undergone major increases in the 2000's compared to earlier decades. With increases in global warming of 1.5-2°C, heatwaves may be 85% more frequent[11].

[7] Lewis and King, 2015, Dramatically increased rate of observed hot record breaking in recent Australian temperatures, https://doi.org/10.1002/2015GL065793
[8] Lewis et al., 2019, Regional hotspots of temperature extremes under 1.5 °C and 2 °C of global mean warming, https://doi.org/10.1016/j.wace.2019.100233
[9] Perkins-Kirkpatrick et al., 2019, The role of natural variability and anthropogenic climate change in the 2017/18 Tasman Sea marine heatwave, https://doi.org/10.1175/BAMS-D-18-0116.1
[10] Oliver et al., 2018, Longer and more frequent marine heatwaves over the past century, https://doi.org/10.1038/s41467-018-03732-9
[11] Trancoso et al., 2020, Heatwaves intensification in Australia: A consistent trajectory across past, present and future, https://doi.org/10.1016/j.scitotenv.2020.140521

The state of the climate using five measures

Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system[12]. Below are a series of five of the latest measures to illustrate the state of the climate, looking at Australian mean annual temperature, Antarctic Sea ice, levels of CO_2, global emissions, and sea surface temperatures.

1. Global greenhouse emissions[13]



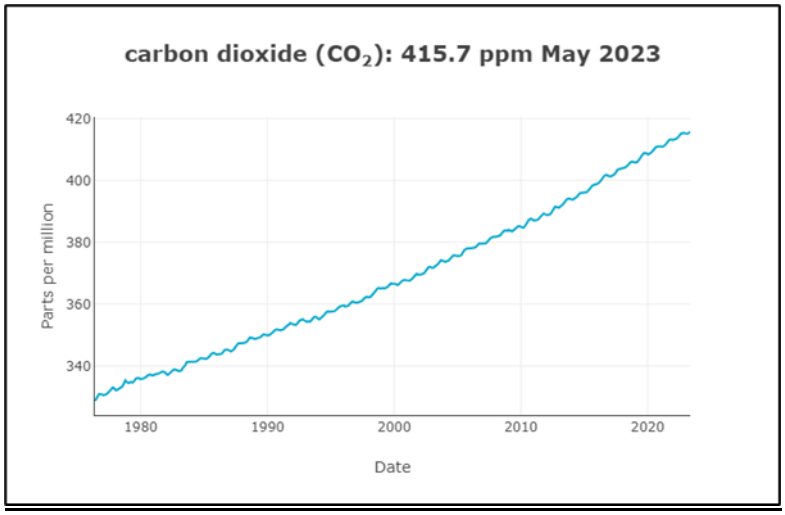
This shows the annual global anthropogenic greenhouse gas emissions by source, from 1970–2021. The trends for greenhouse gasses. CO_2, CH_4 and N_2O emissions continue to increase steadily over this period. Greenhouse gas emissions are a key indicator for human caused climate change. Greenhouse gas emissions are at an all-time high of 54 $GtCO_2e$.

(a). CO2-equivalent emissions in **(a)** and **(f)** are calculated using global warming potentials (GWPs) with a 100-year time horizon from the AR6 WGI Chap. 7. Source: Forster et al., 2023.

[12] CSIRO, 2020, Climate change in Australia, https://www.csiro.au/en/research/environmental-impacts/climate-change/Climate-change-information

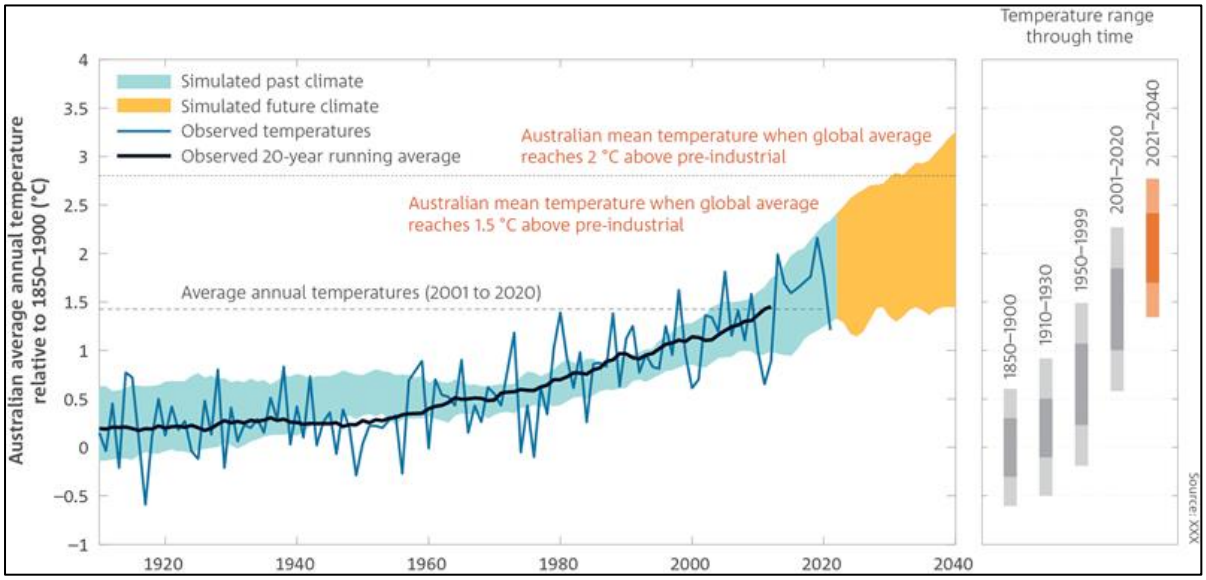
[13] Forster et al., 2023, Indicators of Global Climate Change 2022: annual update of large-scale indicators of the state of the climate system and human influence, https://doi.org/10.5194/essd-15-2295-2023

2. Atmospheric carbon dioxide[14]



As of May 2023, atmospheric carbon dioxide reached 415.7 parts per million for the monthly mean baseline greenhouse gas concentrations measured at the Kennaook / Cape Grim Baseline Air Pollution Station, Tasmania. Air masses arriving at the Kennaook / Cape Grim station have typically travelled for many thousands of kilometres across the Southern Ocean. This air is free from recent human and terrestrial influences and is very well mixed, meaning it represents the background or 'baseline' atmospheric composition for the mid-latitudes of the Southern Hemisphere. The long-term changes in baseline atmospheric composition are the principal drivers of climate change. Source: CSIRO.

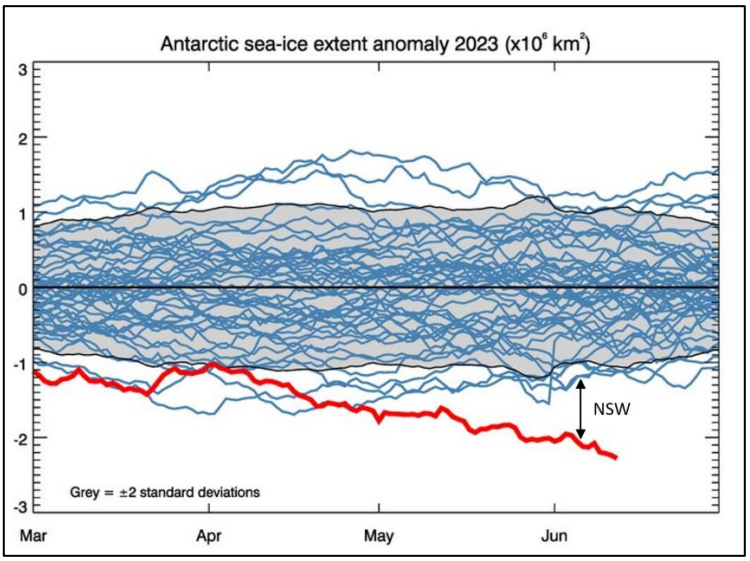
3. Temperature rise[15]



Australian average annual temperature in observations and global climate models shown relative to the 1850–1900 baseline approximating the pre-industrial era. Past and future-coloured bands show the 20-year running average from models for historical conditions and all plausible future scenarios to 2040. Black dashed lines show the approximate average warming expected for Australia when the global average temperature reaches 1.5 and 2.0 °C above the pre-industrial era. The panel to the right shows the range of temperatures (one and two standard deviations) in various epochs from observations and the 2021–40 period as simulated by one climate model (the results from which broadly reflect the mean of all models). Source: CSIRO.

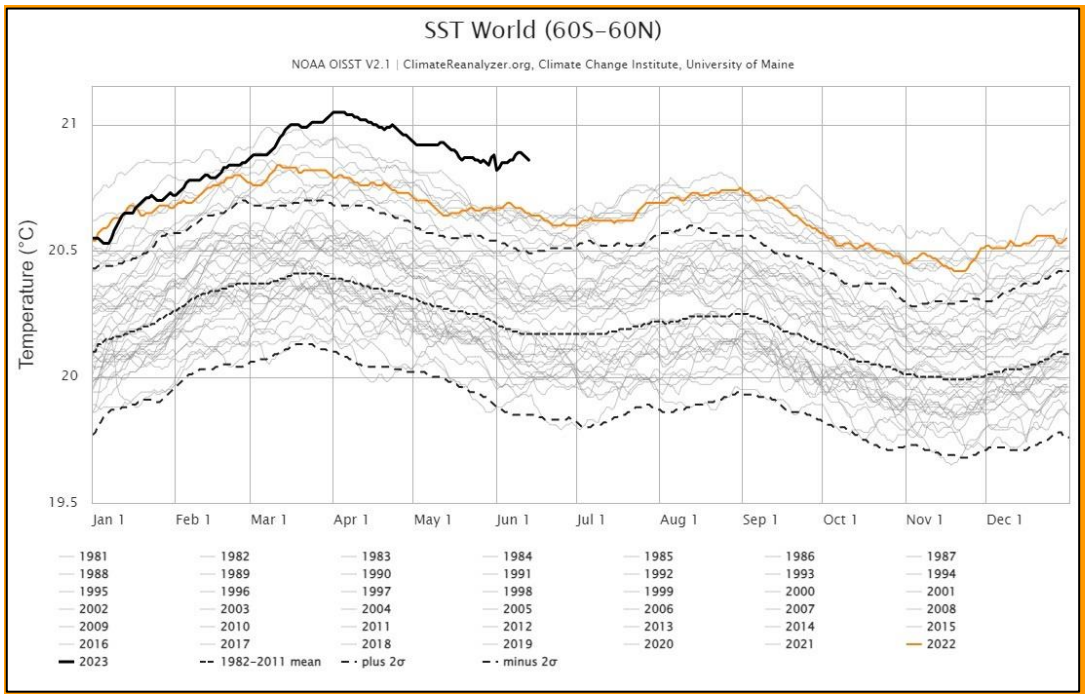
[14] National Oceanic and Atmospheric Administration, 2023, Broken record: Atmospheric carbon dioxide levels jump again, https://www.noaa.gov/news-release/broken-record-atmospheric-carbon-dioxide-levels-jump-again
[15] Bureau of Meteorology and CSIRO, 2022, State of the Climate 2022, http://www.bom.gov.au/state-of-the-climate/

4. Antarctic Sea Ice[16]



As mid-winter approaches, Antarctic sea-ice extent remains at record low values. The blue lines indicate each year in the satellite record, the red line 2023. The difference in sea-ice extent from previous years is currently equivalent to the area of New South Wales. Antarctic sea ice cover has been very low since 2016, with summer areas not observed since the beginning of satellite records in the 1970s – a phenomenon that is concerning the scientific community and one that is currently not well understood. Source: Phil Reid, BoM.

5. Ocean temperatures[17]



Ocean surface temperatures have hit an all-time high, breaking all records since measurement began in the 1980s. Temperatures reached a global average of 21.1°C in April 2023. Source: University of Maine.

[16] Australian Antarctic Partnership, 2023, Polar scientists call for urgent action in view of rapid Arctic and Antarctic change, https://aappartnership.org.au/polar-scientists-call-for-urgent-action-in-view-of-rapid-arctic-and-antarctic-change/
[17] Climate Reanalyzer, 2023, Daily Sea Surface Temperature, https://climatereanalyzer.org/clim/sst_daily/

Towards emissions reduction

Australia's climate has warmed by 1.47 ± 0.24°C since 1910[18], slightly faster than global average warming. The first two decades of the 21st century were both warmer than any decade in the 20th century. Australian surface temperatures will continue to rise until at least 2050 under all emission scenarios and further increases in climate extremes are inevitable[19].

Australia's emissions reduction target of 43% below 2005 levels by 2030 and reaching net zero emissions by 2050 is a positive signal of climate action. It is pleasing to see the government's policy priorities working towards a low emissions economy, as well as other tangible positive efforts to address climate change across all government portfolios including finance and agriculture. The recent commitment to legislate a national Net Zero Authority[20] indicates the government is working towards net zero.

However, Australia's climate targets are well below those advised by the IPCC, the UN Environmental Programme and compared to a host of other industrialised G7 countries including the United Kingdom: the UK commits to reducing economy-wide greenhouse gas emissions by at least 68% by 2030 compared to 1990 levels, and the European Union: a net domestic reduction of at least 55% in greenhouse gas emissions by 2030 compared to 1990[21].

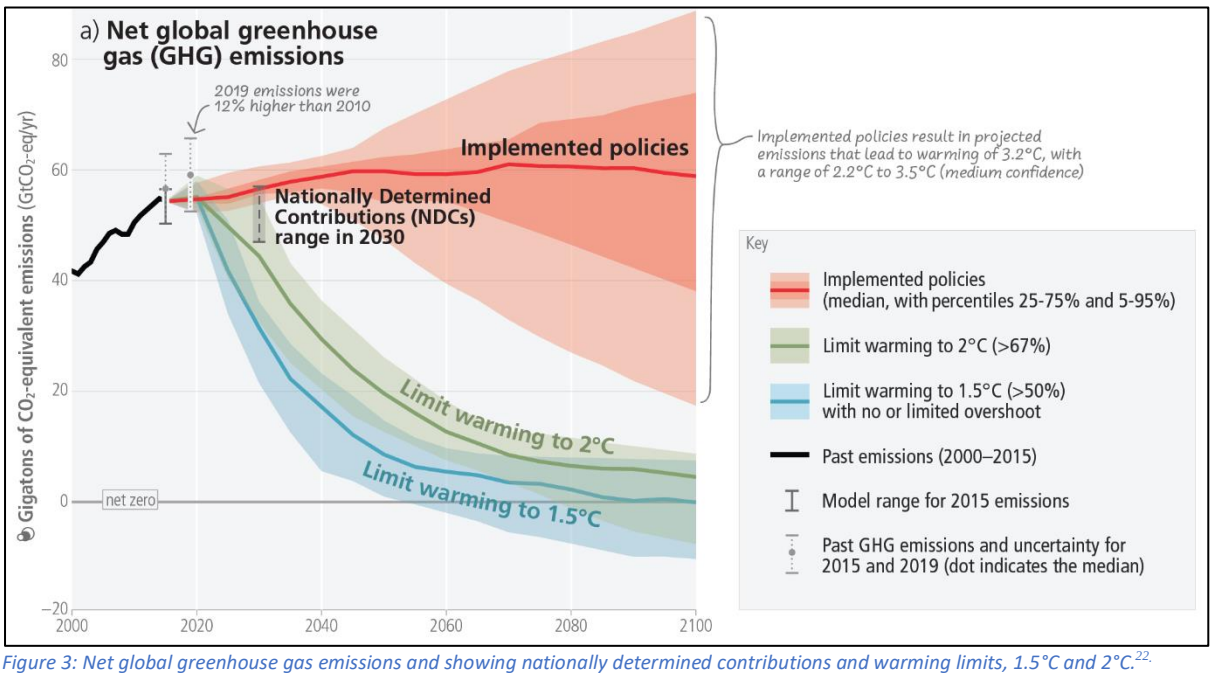


Figure 3: Net global greenhouse gas emissions and showing nationally determined contributions and warming limits, 1.5°C and 2°C.[22]

The United Nations Emissions Gap Report 2022[23] highlights the current discrepancy between national targets and the goals of the Paris Agreement (to limit global warming to well below 2°C and

[18] Bureau of Meteorology and CSIRO, 2022, State of the Climate 2022, http://www.bom.gov.au/state-of-the-climate/
[19] Herold et al., 2021, Projected changes in the frequency of climate extremes over southeast Australia, Environmental Research Communications, https://doi.org/10.1088/2515-7620/abe6b1
[20] Prime Minister of Australia, 2023, Appointment of Net Zero Economy Agency and Advisory Board, https://www.pm.gov.au/media/appointment-net-zero-economy-agency-and-advisory-board
[21] Climate Watch, 2023, Australia| United Kingdom| European Union (27) | Compare climate targets, https://www.climatewatchdata.org/custom-compare/overview?targets=AUS-revised_first_ndc,GBR-revised_first_ndc,EUU-
[22] IPCC, 2023, Summary for Policymakers. In: Climate Change 2023: Synthesis Report. A Report of the Intergovernmental Panel on Climate Change. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC_AR6_SYR_SPM.pdf
[23] United Nations Environment Programme, 2022, Emissions Gap Report 2022: The Closing Window — Climate crisis calls for rapid transformation of societies — Executive Summary, https://www.unep.org/emissions-gap-report-2022

pursue efforts to restrict warming to 1.5°C[24]). If countries achieve their current Nationally Determined Contributions, warming will still reach 2.4-2.6°C[25] which would have catastrophic impacts on many economic and environmental systems. The IPCC Synthesis report states that limiting warming to 1.5°C and 2°C involves rapid, deep and in most cases immediate greenhouse gas emission reductions[26].

Australia's progress

In the latest quarterly update of Australia's greenhouse gas emissions to December 2022[27], national emissions were 463.9 Mt CO_2-e. The annual emissions target for 2030 is 354 Mt CO_2-e. The 2022 total emissions for Australia decreased by only 0.4% or 2 Mt compared to 2021 levels[28].

The Federal Minister for Climate Change, Chris Bowen echoed the need for rapid action to meet the target, stating the 'decarbonisation rate needs to be at least 17 million tonnes of carbon per year.' This would require a 40% faster rate of decarbonisation. The chair of the Climate Change Authority, Grant King has said 'Australia needs to be moving faster and across all sectors of the economy to achieve our targets'[29].

The Department of Climate Change, Energy, the Environment and Water's own data on greenhouse gas emissions levels[28] and Australia's current progress demonstrate that considerable action is required to reduce emissions, to meet our 2030 target and our Nationally Determined Contribution in accordance with the Paris Agreement.

[24] United Nations Framework Convention on Climate Change.2015. Paris Agreement. https://unfccc.int/sites/default/files/english_paris_agreement.pdf

[25] United Nations Environment Programme. 2022. Emissions Gap Report 2022. https://www.unep.org/resources/emissions-gap-report-2022

[26] IPCC_AR6_SYR_SPM.pdf

[27] Australian Government Department of Climate Change, Energy, the Environment and Water, 2023, Quarterly Update of Australia's National Greenhouse Gas Inventory: December 2022, https://www.dcceew.gov.au/climate-change/publications/national-greenhouse-gas-inventory-quarterly-update-december-2022

[28] Australian Government Department of Climate Change, Energy, the Environment and Water. 2022. Quarterly Update of Australia's National Greenhouse Gas Inventory. https://www.dcceew.gov.au/sites/default/files/documents/nggi-quarterly-update-dec-2022.pdf

[29] ABC News, 2022, Federal government releases first 'climate change statement', but Australia remains behind on emissions targets, https://www.abc.net.au/news/2022-12-01/climate-change-statement-emissions-target/101721014

Q1. What actions and enablers beyond those identified in the Strategic Framework could help Australia progress towards a prosperous and resilient net zero future? What are your highest priorities?

The journey to a net zero future is already underway. Inevitably this means changes to existing work practises for many sectors. Our experience at the ARC Centre of Excellence for Climate Extremes has allowed us to develop, contribute and apply our expertise to the existing body of climate science knowledge. Although our expertise lies in fundamental climate science, we continue to receive requests for information from decision makers for climate scenario information. Climate science is rightly seen as the beginning of the supply chain for climate information.

Global climate models are critical tools for decision-making around water, energy, carbon, natural disaster management and resilience, for those targeting mitigation and adaptation investment. However, climate models are developed to help understand how the climate system works. Current models lack the spatial detail to connect global climate change to local-scale impact; they lack the spatial detail to assess climate risk and evaluate the benefits of mitigating emissions and local climate change adaptation. Harnessing the value of next generation climate models requires scientific ambition, coordination, high-performance computing and high-performance data infrastructure. Without this, Australia risks investing in major strategies around net zero that fail, while missing the identification of strategies that would have worked.

More reliable projections of future climate extremes, such as cyclones, hail, extreme winds, storm surge, and flood require climate models to be detailed enough to resolve weather scales (1km – 10km). At present, in Australia, it is possible to run a limited number of global coupled climate simulations at ~10km in "experiment mode" as a proof of concept, but only for specific years. Many such simulations covering the 20th and 21st century would be needed to properly address the key uncertainties that would underpin a rigorous risk assessment, or to identify specific strategies that optimise a net zero strategy. The climate simulations required necessitates a national coordination of expertise, which is currently lacking, aligned with a national strategy for understanding climate risk which is also currently lacking. It would require major software engineering activities that Australia has now put in place via the ACCESS National Research Infrastructure and welcome funding via NCRIS. Finally, it would require a clear strategy for national supercomputing and high-performance data infrastructure; Australia has struggled to develop a clear view of a national strategy in these areas. In short, without a coordinated national climate modelling strategy, integrated with a national supercomputing and high-performance data infrastructure strategy Australia risks failing to achieve its net zero ambition through lack of scientific understanding.

We also highlight that decision makers require an increased level of understanding and literacy of climate information to fully utilise the nature, meaning, accuracy and uncertainty of climate data. The climate risk for each application is very different. For example, the information used to inform the climate risk associated with the Australian road network can be very different to the information used to assess the vulnerability of a wetland. The requests for information we have received demonstrate a growing need for fit for purpose climate information to assess climate risk and hence climate activities for mitigation and adaptation. Mitigation and adaptation activities are becoming part of business requirements, and increasingly decision makers are looking for climate information. An assessment of climate risk is usually the starting point making this a pivotal first step.

We suspect the Australian Climate Service will become a crucial element in helping users navigate the climate change, climate risk, mitigation and adaptation ecosystem. We note there is a clear need for information and education in this area across all sectors. Without this, there is the potential for at best ill-informed policy outcomes and at worst dangerous and unscrupulous activities - a wild

west of climate activities and initiatives. Unfortunately, we are not clear on the role the Australian Climate Service will play in this area, and consultation from the Australian Climate Service to the University sector is almost entirely lacking.

Authors: Borowiak, A., Cranko Page, J., Falster, G. M., Greco, I., Hobeichi, S., Huneke, W.G.C., Isphording, R., Jeffree, J., Patel, R. S., Pathmeswaran, C., Poddar, S., Reid, K.J., Udy, D.G.,

The response to questions 2 and 4 were written by postdoctoral researchers and PhD candidates (hereafter *early career researchers; ECRs*) at the Australian Research Council Centre of Excellence for Climate Extremes (the Centre). They are the emerging climate scientists who were all keen to express their views on setting emissions targets for Australia. Their views are conveyed below.

A Response from the Frontline

As early career climate scientists in Australia, we have a crucial perspective on Australia's emissions reduction targets. We are experts in climate science whose research aims to enrich the nation's understanding of Australian climate risks throughout the community. However, projections are not purely academic to us, as younger scientists, we will also live through the impacts we study. At the current rate of greenhouse gas emissions and associated warming, we are likely to witness the death of the Great Barrier Reef and experience more intense and frequent extreme weather[30]. Our acute knowledge of these impacts and the uncertainty of rapidly achieving net-zero poses a dramatic burden on our mental health and wellbeing. We work on the frontline and have dedicated our lives to understanding climate change risks. Yet, the physical and financial costs of inadequate action in the present will be consigned to our generation's ledgers.

For these reasons, we call upon the Australian Government to set and deliver ambitious emissions reductions targets in-line with the Intergovernmental Panel on Climate Change (IPCC). Reaching net-zero is a requirement for stabilising human-induced global temperature increases and associated adverse impacts. Ultimately, the sooner we reach net-zero, the greater the chance we have of maintaining a safe and habitable Earth for all of us.

Q2: How are you and the people around you impacted by or preparing for the net zero transition and Australia's climate future? How can governments better support you to prepare for or respond to the impacts?

Rational Trepidation

Climate change and the net-zero transition are the defining challenges of our generation. The path to net-zero affects most aspects of our lives: the jobs we work[31], the food we eat[32], the energy we use[33], and the cities and towns in which we will live[34].

However, the failure to achieve net-zero by 2050 will have a far greater impact upon our lives than the path to get there. As climate scientists, we are acutely aware of the impacts that each year of delay costs the planet and us. We spend our working days conducting the experiments and analysing the data. In the last three years, ECRs from the Centre have expanded humanity's knowledge on the

[30] IPCC, 2022, Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/

[31] Mayfield et al, 2023, Labor pathways to achieve net-zero emissions in the United States by mid-century, Energy Policy, https://doi.org/10.1016/j.enpol.2023.113516

[32] Willett et al., 2019, Food in the Anthropocene: the EAT–*Lancet* Commission on healthy diets from sustainable food systems, https://doi.org/10.1016/S0140-6736(18)31788-4

[33] International Energy Agency, 2022, World Energy Outlook 2022, https://www.iea.org/reports/world-energy-outlook-2022

[34] Australian Government Department of Agriculture, Water and the Environment, 2021, National Climate Resilience and Adaptation Strategy 2021-2025, https://www.agriculture.gov.au/sites/default/files/documents/national-climate-resilience-and-adaptation-strategy.pdf

increasing occurrence of terrestrial and marine heatwaves[35], the changing risk of droughts[36] and flooding rains[37], southeast Australian bushfires[38], and the increasing risk of compound events in a warmer world[39].

In the face of such in-depth knowledge of the problem and immersion in its mechanics, delays in the delivery of a solution provoke understandable and well-justified anxiety. Knowing the trajectory of our climate under our current regime leaves us with rational trepidation about the future and influences our choices every day.

As Australia finally becomes increasingly aware of the existing impacts of our changing climate, some of this anxiety is tempered by a sliver of hope. Taking steps towards net-zero have been shown to reduce climate anxiety[40]. Therefore, seeing the Australian Government implement systematic changes necessary for a net-zero future is critical. Just as every new fossil fuel project approved feels devastating, every decarbonisation project is a victory. As we mentally prepare ourselves for the increasingly troubling future, the Australian Government can support us by doing their part to ensure that the projected future does not become a reality.

The Importance of Education

We recognise the importance of education and outreach in facilitating the transition to net-zero carbon emissions within our communities. Therefore, we embrace our role as scientists in educating our community through public talks and industry engagement. In particular, we are dedicated to enhancing climate literacy in high schools by running workshops for teachers. In these workshops, we equip teachers with up-to-date climate change research and empower them with the tools to convey this knowledge to their students. Our goal is to ensure that the future generation is well-informed about climate change and can think innovatively to address this global challenge.

We suggest the following measures the government can take to support our work advancing climate education: include climate education in school curricula; support the development of climate education to ensure that the content is up-to-date and aligned with scientific consensus; allocate funding to train teachers.

As a starting point, the government could facilitate the organisation of a climate education summit. This summit would serve as a platform for educators, scientists, policymakers, and other stakeholders to share best practices, exchange knowledge, and collaborate on strategies for integrating climate education into school curricula.

How could governments better support us as researchers?

As climate researchers, we spend years seeking answers to complex questions related to climate change impacts and potential mitigation and adaptation strategies. Despite conducting advanced research on climate risk in Australia, our PhD researchers are paid below minimum wage[41]. After obtaining a PhD, postdoctoral researchers face years of insecure work on short-term contracts due to

[35] Pathmeswaran et al., 2022, Exploring Potential Links Between Co-occurring Coastal Terrestrial and Marine Heatwaves in Australia, https://doi.org/10.3389/fclim.2022.792730
[36] Hobeichi et al., 2022, Towards a Robust, Impact-Based, Predictive Drought Metric, Water Resources Research, https://doi.org/10.1029/2021WR031829
[37] Reid et al., 2021, Extreme Water Vapor Transport During the March 2021 Sydney Floods in the Context of Climate Projections, Geophysical Research Letters, https://doi.org/10.1029/2021GL095335
[38] Jyoteeshkumar reddy et al., 2021, Modulating influence of drought on the synergy between heatwaves and dead fine fuel moisture content of bushfire fuels in the Southeast Australian region, Weather and Climate Extremes. https://doi.org/10.1016/j.wace.2020.100300
[39] Ridder et al., 2022, Increased occurrence of high impact compound events under climate change, NPJ Climate and Atmospheric Science, http://dx.doi.org/10.1038/s41612-021-00224-4
[40] Fyke et al., 2023, Reducing personal climate risk to reduce personal climate anxiety, Nature Climate Change, https://doi.org/10.1038/s41558-023-01617-4
[41] Garland and Belward, 2022, How are PhD students meant to survive on two-thirds of the minimum wage? https://theconversation.com/how-are-phd-students-meant-to-survive-on-two-thirds-of-the-minimum-wage-185138

the scarcity of jobs in Australia and reduced University funding[42]. By investing in research, the Australian government can demonstrate their recognition of the importance of climate action.

However, effective action requires not only research but also policy implementation, regulatory frameworks, and collaboration with various stakeholders. The Government must strive to bridge the gap between research and action by using insights gained from research to underpin evidence-based policy decisions. By aligning research findings with policy and action, governments can better support individuals and communities in preparing for and responding to the impacts of climate change. We believe these two challenges represent an opportunity for a broader grants scheme that encourages sharing research findings beyond academic circles and connects researchers with policy makers.

Q4: What more could the Government do to help you reduce your carbon footprint?

We spend our days researching the impacts of climate change, but in our personal capacity it is difficult to live sustainably within our current structures. While we acknowledge that individual efforts do matter, we want to highlight that the concept of an individual *carbon footprint* is a rhetorical technique used by large-scale emitters to abdicate responsibility for the climate crisis[43]. Unsustainable individual carbon footprints are a symptom of decades of inaction related to government policy and budget priorities that disincentivise structural change. For example, students at MIT calculated the carbon footprint for a homeless man with no car, who lives in a homeless shelter and eats at soup kitchens, and it was still unsustainably high[44].

In other words, no matter how much an individual cuts from their own personal emissions, they cannot reduce their carbon footprint to sustainable levels while fossil fuels form the basis of our country's energy production and supply chains.

We therefore believe Question 4 is poorly phrased, and we ask instead for rapid growth in infrastructure that allows freedom from fossil fuels on a national level. Such infrastructure developments include but are not limited to: the expansion of renewable energy[45] and public transport; solar panels on all car parks connected to electric charging stations[46]; protected bike lanes and 15-minute cities[47]; and improved energy efficiency of existing and new buildings[48].

Finally, while building the infrastructure required to reach net-zero poses a huge financial burden initially, the cost of doing nothing will be more expensive than acting quickly to achieve net-zero[49]. Additionally, these infrastructure changes have benefits beyond the overall objective of achieving net-zero for limiting climate impacts. Such benefits include improved mental and physical health, easing the cost-of-living pressures, and Australian self-sufficiency and security.

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[42] Parliament of Australia, 2022, Higher Education Budget Review 2021-22 Index, https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/BudgetReview202122/HigherEducation#:~:text=Funding%20trends&text=1%3A%202021%E2%80%9322%20(p,%E2%80%9322%20to%202024%E2%80%9325.

[43] Supran et al., 2021, Rhetoric and frame analysis of ExxonMobil's climate change communications, One Earth, https://doi.org/10.1016/j.oneear.2021.04.014

[44] Chandler, 2008, Leaving our mark, MIT News, https://news.mit.edu/2008/footprint-tt0416

[45] Gilmore et al., 2022, Clean energy futures: An Australian based foresight study, Energy, https://doi.org/10.1016/j.energy.2022.125089

[46] Ryan, 2022, France's plan for solar panels on all car parks is just the start of an urban renewable revolutioin, https://theconversation.com/frances-plan-for-solar-panels-on-all-car-parks-is-just-the-start-of-an-urban-renewable-revolution-194572

[47] Patterson, Barrie, 2023, Forget the conspiracies, 15-minute cities will free us to improve our mental health and wellbeing, https://theconversation.com/forget-the-conspiracies-15-minute-cities-will-free-us-to-improve-our-mental-health-and-wellbeing-200823

[48] Bell et al., 2022, Future climate scenarios and their impact on heating, ventilation and air-conditioning system design and performance for commercial buildings for 2050, Renewable and Sustainable Energy Reviews. https://doi.org/10.1016/j.rser.2022.112363

[49] Kompas, Pham and Che, 2018, The Effects of Climate Change on GDP by Country and the Global Economic Gains From Complying With the Paris Climate Accord, https://doi.org/10.1029/2018EF000922

The technology needed to achieve net-zero already exists[50]. All we require is the political will.

5. What are the other challenges and opportunities the global context presents Australia with in responding to climate change?

Maintaining and enhancing climate and weather research capability

Australia's research capacity is critical to understanding how the climate is reacting to and being impacted by increased warming. Our need to progress to net zero is guided and measured by climate science. It is therefore paramount that Australia re-builds its capacity as a nation for the short and long term. The ARC Centre of Excellence for Climate Extremes is amongst many organisations (including the Bureau of Meteorology, the Australian Climate Service, CSIRO and research organisations worldwide) who support and develop research expertise. However, the last decade has seen a major re-focus of activities into the development of products, and applied research. The investment in the fundamental research, that provides long-term capacity development, has been declining dramatically in Australia and is now below the level required to sustain critical capabilities.

The lack of a national strategy, the lack of national coordination, the lack of any national funding environment for basic climate science places our ability to respond to climate change at fundamental risk. Without this coordination and investment, we will not know what we should be responding to.

Australian climate modelling

The Australian suite of models – the Australian Community Climate and Earth System Simulator (ACCESS) is supported by a consortium of Universities, CSIRO, the Bureau of Meteorology and crucially the ACCESS National Research Infrastructure Facility funded via the National Collaborative Research Infrastructure Strategy (NCRIS). This is an important and large-scale endeavour with key components of the ACCESS model from the UK Meteorological Office and the US Geophysical Fluid dynamics Laboratory (GFDL) at the National Oceanic and Atmospheric Administration (NOAA). Critically Australia adds ocean biogeochemistry and land surface processes developed in Australia to this modelling system – these two elements are fundamental to any scientifically-informed strategy around using oceans or the land surface to store carbon.

The long-term health of Australian climate modelling begins with nationally coordinating observations sustained long term. Data collected by the Bureau of Meteorology, CSIRO (particularly greenhouse gas measurements at Cape Grim), data from the Integrated Marine Observing System and from the Terrestrial Environmental Research Network are fundamental. The on-going support for these initiatives provides the foundation for all other activities.

Next, the long-term health of Australian climate modelling requires human resources – researchers trained in Math, Physics, Computer Science and data science working collaboratively. At present, organisations are effectively encouraged to compete which, in a resource constrained world, does not maximise Australia's capacity to build resilience. Funding is siloed (an exception here is the National Environmental Science Program which is explicitly collaborative across institutions), short term (3 years typically) and tends to down-play high-risk research. Perhaps most crucially, most research organisations in Australia have lost ambition, lost a willingness to embark on high impact research that might take a decade. This sharply contrasts with US, UK and European strategies and leaves Australia vulnerable to failing to identify immediate risks to our own region.

[50] Pascale et al., 2023, 'Modelling Summary Report', Net Zero Australia, https://www.netzeroaustralia.net.au/wp-content/uploads/2023/04/Net-Zero-Australia-Modelling-Summary-Report.pdf

A national strategy for responding to climate change needs to design a national science program that coordinates research, aligns that research through the ACCESS system to directly address key adaptation risks.

Q9. What should Australia's 2035 target be and why?

There is a linear relationship between cumulative emissions of CO_2 by human activities and the magnitude of global warming above pre-industrial levels. This relationship means that each additional tonne of CO_2 emitted leads to an incremental temperature increase. Achieving net-zero CO_2 emissions is required to halt human-induced warming of the climate. This relationship is known as the Transient Climate Response to Cumulative CO_2 Emissions (TCRE) and provides the geophysical basis for quantifying the remaining carbon budget for limiting warming this century to a particular level.[51]

The IPCC 6th Assessment report determined the remaining CO_2 budget from the start of 2020 for limiting warming to various policy-relevant levels, with varying degrees of certainty. Global CO_2 emissions since that time, as well as updated scientific evidence, has further reduced the global carbon budget. The table below provides a peer-reviewed update (based on IPCC methodology) on the remaining global carbon budget at the start of 2023 for limiting human-caused climate warming[52]:

Warming level	50% chance of success	66% chance of success	83% chance of success
1.5°C	250 Gt CO_2	150 Gt CO_2	100 Gt CO_2
1.7°C	600 Gt CO_2	500 Gt CO_2	350 Gt CO_2
2.0°C	1150 Gt CO_2	950 Gt CO_2	800 Gt CO_2

The remaining carbon budgets are based on CO_2 emissions, with the requirement that other non-CO_2 greenhouse gas emissions are also reducing over time, aligned with the global transition to net-zero CO_2 emissions. The carbon budget assumes that between 2020-2050 there will be a 50% reduction in CH_4 emissions, a 25% reduction in N_2O emissions, and a 77% reduction in SO_2 emissions. If these non-CO_2 emission reductions are not achieved, then the remaining CO_2 budget will be smaller than the value given in the table above.

Staying within the global carbon budget for limiting warming requires international cooperation and action. Translating the global budget to national allocations requires the determination of "fair share" national budgets. Fairness principles should consider aspects of "responsibility", "equality" and "capability"[53]. Previous work by Australia's Climate Change Authority determined that from 2013 onwards Australia's fair share should equate to 0.97% of the global CO_2 emissions budget[54]. Between 2013-2022 Australia's CO_2 emissions have been 1.13% of global emissions over the same time[55].

Ignoring the exceedance of Australia's nationally determined "fair share" over the past decade, applying the 0.97% share to the global CO_2 budgets above can provide guidance on Australia's

[51] Matthews, H.D., Tokarska, K.B., Nicholls, Z.R.J. *et al.* Opportunities and challenges in using remaining carbon budgets to guide climate policy. *Nat. Geosci.* **13**, 769–779 (2020). https://doi.org/10.1038/s41561-020-00663-3. https://rdcu.be/dcBV3
[52] Forster et al., 2023, ESSD, https://doi.org/10.5194/essd-15-2295-2023
[53] Matthews, H.D., Tokarska, K.B., Nicholls, Z.R.J. *et al.* Opportunities and challenges in using remaining carbon budgets to guide climate policy. *Nat. Geosci.* **13**, 769–779 (2020). https://doi.org/10.1038/s41561-020-00663-3. https://rdcu.be/dcBV3
[54] Climate Change Authority (2014) Reducing Australia's Greenhouse Gas Emissions— Targets and Progress Review Final Report
[55] Based on Global Carbon Project 2022 data: Friedlingstein et al., 2022, ESSD, https://doi.org/10.5194/essd-14-4811-2022

remaining share of the carbon budget for limiting warming to well below 2°C. From 2023 these are the total CO_2 budgets remaining for Australia:

Warming level	50% chance of success	66% chance of success	83% chance of success
1.5°C	2425 Mt CO_2	1455 Mt CO_2	970 Mt CO_2
1.7°C	5820 Mt CO_2	4850 Mt CO_2	3395 Mt CO_2
2.0°C	11155 Mt CO_2	9215 Mt CO_2	7760 Mt CO_2

These remaining CO_2 budgets for Australia should be used to guide a science-based approach to determining Australia's 2035 NDC. A science-based approach would account for reduction of the remaining carbon budget through projected CO_2 emissions between 2023-2030 and projected reductions in non-CO_2 greenhouse gases, to then determine the emission reduction target required for 2035, as well as the year when Australia's emissions will need to reach net zero to stay within our remaining carbon budget.

Q11. What are some leading indicators of progress towards preparing for and adapting to climate change?

First, to prepare for and adapt to climate change requires a robust understanding of the changes to be expected. This robust understanding does not exist in Australia; whether rainfall will increase or decrease under warming is unknown across most of the continent. Inconvenient as it may be our knowledge of what we need to prepare for is not as well developed as might be hoped.

There are some specific indicators of progress, however. Numerous climate change indicators exist in the form of levels of greenhouse gases, warming projections, carbon budget data as well as national inventories and targets. However, along with this data, other factors need to be considered to ensure preparedness and adaptation are adequate.

Compound events

Compound events involve multiple elements of weather and climate occurring simultaneously and causing an impact on a socioeconomic or ecological system[56,57]. They should be considered in risk assessments when exploring future climate risk and adaptation.

Compound events may arise from multiple hazards or drivers or may be a succession of hazards, hazards in multiple connected locations, or simply a more severe event as the result of preconditioning. For example, an increase in rainfall or in wind gusts of 10% in isolation are unlikely to be significant. However, occurring simultaneously the impact can be considerable. An East Coast Low affecting the Sydney Basin can increase water storages. Three East Coast Lows affecting the Sydney Basin within a few weeks could be catastrophic.

Australia has experienced a variety of compound events that have led to loss of life and negatively impacted the Australian economy over the past decades. Future climate change will lead to an increase in prolonged hot and dry compound events over all of Australia which is likely to exacerbate fire risk and have negative impacts on agricultural productivity and human health. Current climate

[56] ARC Centre of Excellence for Climate Extremes, 2022, A new global picture of compounding weather and climate hazards, https://climateextremes.org.au/a-new-global-picture-of-compounding-weather-and-climate-hazards/
[57] ARC Centre of Excellence for Climate Extremes, 2022, Why research on compounding weather and climate hazards is important, https://climateextremes.org.au/why-research-on-compounding-weather-and-climate-hazards-is-important/

models project an increase in wet and windy compound events in the northern parts of Australia dominated by tropical cyclones and thunderstorms, and a decrease in events in the south where fronts and frontal systems are the dominant drivers of extreme wind and rain.

Our understanding of many compound events is insufficient to reliably assess the risk they pose. Current observational records are not sufficiently long and/or are too sparse to perform reliable statistical analyses. This means that we cannot be certain how well our climate models reproduce the interactions at play. The ARC Centre of Excellence for Climate Extremes continues to incorporate compound event research into its program of research.

Assessing physical climate risk

The impact of severe weather on Australia has often been destructive, including the impacts of floods or extreme temperatures. As weather related disruptions become more significant with climate change, the extent to which this translates into risks depends upon the exposure to the hazard. We are exposed to multiple risks depending on our location and the vulnerability.

A review of current hazards including climate exposure can provide assurance for policy decisions and actions. However, it is important to provide a rationale for decisions before any investment. Any analysis or interpretation of climate hazard data to inform climate resilience decisions should performed cautiously and with expert help under a robust governance framework. Technical expertise can provide advice and produce information and guidance and should be undertaken with the help or through the climate science community. It is important to convey information in a useful way, for example, describing hazard exposure through ranges such as: severity, likelihood, duration, and frequency, confidence. This helps to convey uncertainty in a meaningful way, rather than simply providing quantitative information.

Assessing physical climate risk through an initial assessment of current exposure using historical observed severe weather events can provide a useful starting framework for a risk assessment. A storyline approach to future climate scenarios can provide an extension to this assessment and include multiple lines of evidence for a qualitative defensible approach focussing on future risk. These strategies are necessarily customised unfortunately.

A potential governance framework should record and provide assurance around climate data including methodology, assumptions, sources of data and the resolution required. Assessing risk should be asking the following questions of climate information: what was used, where it came from, how it was generated and how uncertainty is communicated.

Climate data

As outlined above, climate data can inform standards and design requirements in the context of uncertainties around different possible futures. However, climate data for projections is unable to provide robust quantitative data around such defined concepts such as locations or moments in time. Using climate projections can provide very helpful guidance around future risk, but not reliably enough to identify exact locations. These might be defined using information such as topographic data, or soils data. Once defined, aspects of climate risk could be added in useful ways.

A long-term strategy that harnesses the research capacity of our universities, and the operational capacity of our weather and climate services is required, to enable Australia to join a world-leading initiative to develop the next generation of global climate models.

Computer modelling of the climate system is important for much of this research. For example, detailed modelling is critical to understanding the uptake of heat by the oceans. Planned investment by the Australian Government in research infrastructure to support Australia's climate modelling

capabilities via the National Collaborative Research Infrastructure Strategy (NCRIS) will therefore contribute to greater understanding.

19. What could governments do to help?

1. Undertake a thorough assessment of existing climate science and associated capabilities. This will ensure, in the short term, that decision-makers avoid investment resulting from limited climate model capability and limited scientific understanding. In the long term, this directs research efforts and investment to areas where capabilities can be improved.

2. A national strategy that pulls together existing capabilities to share a common vision of what Australia wants and what capability is needed. This should be step 1 in the creation of a national climate science strategy that feeds through to a national climate modelling strategy to directly inform risk and resilience.

3. A review of training for the next generation of researchers, including funding of PhDs, postdoctoral research fellows and their pathways to a career is long overdue. If Australia wants a national capability – or if Australia wants a southern hemisphere capability – addressing postgraduate funding and postdoctoral research fellow employment is a requirement.