ATTACHMENT 5

Expert Report Regarding the Greenhouse Gas and Climate Implications of the proposed Dendrobium Mine Extension Project (SSI - 33143123)

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1 Preliminaries

1) This expert report (hereafter, this Report) is a response to a brief provided to me by Environmental Defenders Office (hereafter, EDO) on 25 May 2022. Said brief (hereafter the EDO Brief) is annexed to this report as Appendix A.

2) As detailed in the EDO Brief, I understand that this Report has been requested by EDO on behalf of its client, Protect Our Water Catchment, in relation to the proposed Dendrobium Mine Extension Project (hereafter, the Project) by Illawarra Coal Holdings Pty Ltd (hereafter, the Applicant), which is a subsidiary of South32 Limited. In particular, my independent expert advice is sought with regard to the greenhouse gases and climate change impacts associated with the Project.

3) The Project (named SSI 33143123) is an extension of the Applicant's existing underground coal mine located about 8 km west of Wollongong in the Southern Coalfield of New South Wales (NSW), and is a redesign of the Applicant's previous Significant State Development (SSD) application (Dendrobium Extension Project, SSD 8194).

4) I have reviewed Division 2 of Part 31 of the *Uniform Civil Procedure Rules 2005 (UCPR),* and the Expert Witness Code of Conduct contained in Schedule 7 of the UCPR, both of which govern the use of expert evidence in NSW Courts, and I agree to be bound by them in this Report. Specifically, I understand and agree to comply with the expectation that *``An expert witness is not an advocate for a party and has a paramount duty, overriding any duty to the party to the proceedings or other person retaining the expert witness, to assist the court impartially on matters relevant to the area of expertise of the witness.''*

5) External sources used in this Report are referenced. Unless otherwise indicated, modelling work presented in these external sources is taken at face value, as verifying the results is beyond the scope of this Report. Where relevant, underlying assumptions are noted.

6) A curriculum vitae of my relevant qualifications and experience is attached as Appendix B to this report.

2 Executive Summary

7) The primary conclusions of this Report are presented below. Sections of the Report that contain more detail are listed in brackets after each main point.

8) Culminating years of work, the United Nations' Intergovernmental Panel on Climate Change (IPCC) has recently released three assessment reports in its sixth series, one from each of its Working Groups. As a compendium of recent science, these reports form an important evidentiary base and are referred to often in this Report. They are:

   a) Climate Change 2021: The Physical Science Basis (hereafter, AR6 WGI) [1]

   b) Climate Change 2022: Impacts, Adaptation and Vulnerability (hereafter, AR6 WGII) [2] and

   c) Climate Change 2022: Mitigation of Climate Change (hereafter, AR6, WGIII) [3]

9) Unabated climate change is likely to be greatest overall threat to the environment and people of New South Wales (NSW) because it is comprehensively dangerous, global, fundamental, rapid, compounding, self-reinforcing, has delayed effects and, in some cases, including effects currently underway, is irreversible. [Section 3]

10) The current level of global warming is about 1.2 degrees Celsius (°C) above pre-industrial times. For comparison, the temperature difference between ice ages and the intervening periods is about 4°C – 6°C. [Sections 3 and 6.1]

11) Some aspects of the Earth system have already changed irreversibly. Continued warming increases the risk that some subsystems of the Earth will cross `tipping points' that would cause irreversible changes. Some subsystems already show signs of approaching these

[1] IPCC (2021) Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at https://www.ipcc.ch/report/ar6/wg1/

[2] 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, accessed at: https://www.ipcc.ch/report/ar6/wg2/

[3] 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, accessed at: https://www.ipcc.ch/report/ar6/wg3/

transitions, which could accelerate climate change and greatly intensify its impacts, perhaps irreversibly. [Sections 3 and 3.9]

12) Greenhouse gases (GHGs) emitted by human activities are responsible for essentially all of the global warming driving climate change. [Sections 4.1 and 4.3]

13) The primary anthropogenic GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Atmospheric concentrations of all these gases have risen dramatically since the 1960s at an accelerating rate. The level of CO_2, the most important GHG driving current climate change, is now higher than at any other time humans have inhabited Earth. [Section 4.1]

14) All weather effects are affected to some extent by climate change. Scientists are now able to quantity the effect of climate change on many individual events. [Section 4.2]

15) About 90% of the CO_2 emitted by humans each year is from the burning of fossil fuels: coal, gas, and oil. [Section 4.4]

16) There are several inconsistencies in the summary table of GHG estimates provided by the Project's Environmental Impact Statement. This Report provides consistent summary statistics. [Section 5.2]

17) Alternate GHG estimates for the Project are given that consider cases in which (a) no or very little flaring is undertaken, (b) fugitive emissions post-mining are extended to 2050, and (c) fugitive and end-use emissions are included from anticipated post-2030 mining from Area 3. [Section 5.3]

18) Current effects of climate change worldwide include increased severity of storms and heat waves, species extinction, wildfires, coastal inundation from rising sea levels and increased storm surge. Changes are happening rapidly, examples include: [Section 6.1.1]

    a) The Earth's energy imbalance was estimated in mid-2019 to be about 2 to 3 times what it was in mid-2005.

    b) The past seven years have been the hottest seven years on record.

    c) Over just the last two years, precipitation, heat, and wildfire records have been broken across all areas of the globe.

19) Most years in Australia are now warmer than almost any year in the 20th Century. Long-term increases in extreme fire weather and fire-season length are seen across the country. Flash droughts now happen so quickly that farmers find it difficult to adapt. Three billion individual native vertebrates perished in the 2019/20 Black Summer fires. Australians are five times more likely to be displaced by a climate-fuelled disaster than someone living in Europe. The cost of extreme weather disasters in Australia has more than doubled since the 1970s, reaching $35 billion for the decade 2010-2019. Australia has been rated fourth highest in the G20 for economic losses per unit of GDP incurred from extreme weather events over the last 20 years (1999-2018). [Section 6.1.2]

20) NSW has borne the brunt of many of these changes. For example, 37% of the State's rainforests were fire affected during Black Summer, including over half of the Gondwana Rainforests. In some cases, local tipping points in these forests may have already been crossed. The short-term NSW health costs associated with smoke exposure alone is estimated to be $1.07 billion, more than any other state. The 2022 floods have had devastating effects across large portions of the State, some of which are still recovering from Black Summer fires. [Sections 6.1.3]

21) The trajectory of human emissions, particularly between now and 2030, is the most important determinant of how much more climate change is in store. Already, human choices have essentially ensured that 1.5°C of warming will happen in the next two decades. If the current trend of rising emissions continues, in just 80 years, global warming could be 3°C – 4°C above pre-industrial temperatures. [Section 6.2.1]

22) Climate impacts are hitting harder and sooner than previous scientific assessments have expected. [Section 6.2.2]

23) Future impacts depend on the level of warming that is reached, some of which are detailed in Table 1 below. [Sections 6.2.2, 6.2.3, and 6.2.4]

Table 1: Consequences of Global Warming at Different Levels

Warming above the pre-industrial epoch	Some of the Impacts
1.1 – 1.2°C	***This is the current level of warming.*** 47% of local extinctions reported across the globe during last century can be attributed to climate change. Millions of people are displaced annually because of weather/climate disasters. Peak heatwaves that occurred only once per 30 years in pre-industrial times in Australia, can now be expected every 5 years. Most years in Australia are now warmer than almost any year in the 20th century. Some NSW forests are near, or have already crossed, local tipping points that will irretrievably alter those ecosystems. Agricultural areas in NSW now experience runoff reduced by 15%, on average. The frequency of very warm days in Australia has increased approximately fivefold compared to the period 1960-1989. Black Summer wildfires occur in Australia in 2019-20. Similar fires happen in California in 2020 and 2021. Temperatures reach 38°C above the Arctic Circle and 50°C in Canada. Both poles simultaneously experience heatwaves of 30 to 40°C above their normal temperatures in March 2022.
1.5°C	***This level of warming will almost certainly be reached, as early as sometime in the 2030s.*** Peak heatwaves that occurred only once per 30 years in pre-industrial times in Australia, can be expected every 2.7 years. 6% of insects, 8% of plants, and 4% of vertebrates lose over half of their climatically determined geographic living area. What used to be Australia's hottest year on record (2019) is now an average year. NSW has 2 – 4 more heatwave days per year than it currently experiences.
2.0°C	***This level is above the Paris Agreement goal of "holding the increase in global average temperature to well below 2°C above pre-industrial levels."*** 13% of the Earth's surface undergoes complete ecosystem transformations. 99% of the world's coral reefs, including the Great Barrier Reef, are eliminated. The number of insects, plants and vertebrates losing over half of their habitat doubles compared to losses at 1.5°C.

<table>
<tr>
<td>2.0°C (cont.)</td>
<td>
Moderate risk of large-scale singular events leading to climatic tipping points.
The world’s most vulnerable people experience compounding crisis upon crisis.
In Australia, considerably higher risk of impacts compared to 1.5°C with regard to:
a) Water stress and drought,
b) Shifts in biomes in major ecosystems, including rainforests,
c) Changes in ecosystems related to the production of food,
d) Deteriorating air quality,
e) Declines in coastal tourism,
f) Loss of coral reefs, sea grass and mangroves,
g) Disruption of marine food webs, loss of finfish, and ecology of marine species,
h) Heat related mortality and morbidity, and
i) Ozone-related mortality.
Black Summer-like weather conditions are four times more common than in 1900.
Sydney and Melbourne experience summer temperatures of 50°C.
NSW has 4 – 8 more heatwave days per year than it currently experiences.
Agricultural areas in NSW experience runoff reduced by 30%.
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<tr>
<td>3.0°C – 4.0°C</td>
<td>
This level of warming could be a consequence of the world continuing with its current policy settings regarding GHG emissions.
Most of the world’s ecosystems are heavily damaged or destroyed.
Extreme weather events are far more severe and frequent than today.
Large areas of the world become uninhabitable, causing migration and conflict.
Aggregated global impacts significantly damage the entire global economy.
Peak heatwaves that occurred only once per 30 years in pre-industrial times in Australia expected annually.
Megafires to occur in southeast Australia irrespective of whether drought occurs simultaneously.
Many locations in Australia become uninhabitable due to water shortages.
Many Australian properties and businesses are uninsurable. Severe impacts to both flora and fauna cause many of Australia’s ecological systems to become unrecognisable.
Sea level rise transforms Australia’s coastal regions, putting the health and wellbeing of many people at severe risk.
NSW has one to two more heatwave weeks per year than it currently experiences.
Agricultural areas in NSW experience runoff reduced by 45-60%.
Moderately high risk that a cascade of tipping points in the climate system drives the Earth system into a Hothouse Earth state not seen for millions of years, irrespective of humanity’s late attempts to reduce emissions.
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24) The world is emitting greenhouse gases on a trend that would lead to substantially more dangerous climate change. Nations that have committed to reducing emissions by 2030 have done so on average by only 7.5%, whereas a 30% reduction (on 2010 levels) is needed to limit warming to 2°C and a 55% reduction is needed to limit warming to 1.5°C. Australia's 2030 emissions reduction target is consistent with global warming of 4°C if all other countries followed a similar level of ambition, though this would alter if higher 2030 targets are imposed by the new Government. [Sections 7.1 and 7.1.1]

25) Based on current policies as opposed to Paris Agreement pledges, warming could go as high as 3.6°C. [Section 7.1]

26) Only about 8 years remain at current emission levels before the remaining global carbon budget to hold warming to 1.5°C with at least a 67% chance is exhausted. [Section 7.2]

27) In order to have even a 50% chance of holding warming to 1.5°C, 58% of oil, 59% of fossil methane gas, and 89% of coal reserves must not be extracted. Despite this, governments are still planning to produce about 45% more fossil fuels by 2030 than would be consistent with a 2°C pathway and more than double than would be consistent with a 1.5°C pathway. [Section 7.3]

28) The International Energy Agency's global energy sector roadmap for net zero emissions by 2050 lists as a major milestone that no new or extended coal mines be approved, beginning in 2021. [Section 7.3]

29) NSW could play a major role in limiting climate change by quickly reducing its production of fossil fuels, particularly those which are exported. The emissions caused by combusting the black coal NSW produces are three times more damaging to the NSW environment than its own direct emissions. [Section 7.3.2]

30) The Project is inconsistent with holding global warming to well below 2°C and directly works against NSW's ability to close its coal GHG `Production Gap.' [Section 8.1]

31) On 20-year times scales, appropriate when considering the Project's lifetime and GHG emission targets for NSW, Project fugitive GHGs alone would have an effect on the climate equivalent to 21.9 Mt of CO_2, double all the Scope 1 emissions quoted in the EIS for the Project over its lifetime. [Section 8.1.1]

32) Future climate change presents several increased risks to the Sydney drinking water catchment. [Section 8.2]

33) The Dendrobium SSI Extension Project is significant compared to the annual task of meeting NSW's and Australia's 2030 GHG targets. At a minimum, the Project will make it 4.2% more difficult for Australia to meet its (new) 2030 target, and 12.6% more difficult for NSW to meet its 2030 target. [Section 8.3]

34) If even 15% the Project's product coal were used in NSW, the Project's impact on the State's direct emissions would more than double. [Section 8.3]

35) From a scientific perspective, all emissions, including Scope 3 emissions released when fossil fuels are combusted by any end user, must be included when considering environmental and social effects, including environmental and social effects to NSW. Doing so reveals that the Project negates several times over the climate benefit of NSW meeting its 2030 GHG emissions target. [Section 8.3]

36) An argument that the Project's emissions represent a small fraction of national or global emissions is irrelevant and misleading. If individual consent authorities around the world were to accept this argument and act upon it to approve fossil fuel expansion projects, the climate change predicament would, *per force*, continue to worsen. [Section 8.4]

37) The climate change externalities of the Project, will be borne disproportionately by younger and future generations, with no clear recourse or path to remediation. Taken together with the evidence supplied by this Report of the enormous risks posed by global warming surpassing 2°C, including irreversible consequences, and the contribution of the Dendrobium SSI Extension in increasing that likelihood, it is my view that any benefits from the Project are far outweighed by costs borne by the majority of NSW inhabitants, particularly its youngest. [Section 8.4]

3 Why Climate Change is Different to other Threats

38) **Scientists describe the amount of global warming by comparing the average global surface temperature of the Earth now to that in pre-industrial times** (often taken to mean prior to about 1850). An enormous amount of energy (heat) is required to raise the average surface temperature of the entire Earth by even a small amount. It is this large energy increase that drives the major changes in climate being experienced now, by 'super-charging' the Earth's physical systems.

39) Consequently, **climate change impacts can be large even for rather small changes in the global surface temperature**. **The global average temperature difference between glacials (ice ages) and the periods in between (interglacials) is about 4 – 6°C** (Fig. 1).[4]

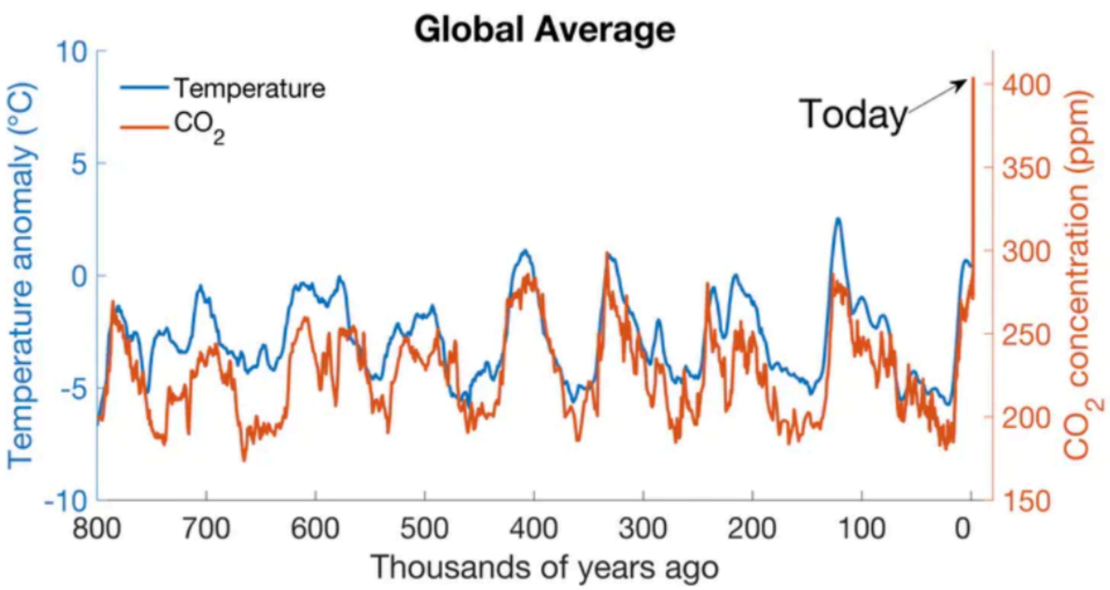

Fig. 1: Global average temperature difference (blue) and atmospheric concentration of CO_2 (orange) over the last 800,000 years. Low periods are ice ages, whilst high periods are interglacials; Only about 5°C separates the two. Plot from Henley and Abram (2017).

[4] Henley, B. and Abram, N. (2017) https://theconversation.com/the-three-minute-story-of-800-000-years-of-climate-change-with-a-sting-in-the-tail-73368, and data sources and references therein

40) Unabated climate change poses an enormous threat to the environment and peoples of the world, Australia and NSW for several reasons that, when taken together, are unique to climate change. Unabated anthropogenic climate change is:

a) **Fundamental** – affecting basic aspects of the physical Earth system, and the ecosystems that depend on it,

b) **Global** – greenhouse gases emitted anywhere in the world affect the whole globe,

c) **Comprehensively Dangerous** – with the potential to disrupt or destroy nearly every ecosystem,

d) **Rapid** – occurring at a speed that precludes many organisms and even whole ecosystems from adapting,

e) **Inertial** – with a delayed response to emissions that `locks in' some measure of climate change greater than that currently experienced,

f) **Compounding** – the effects of climate change do not occur independently, but can occur simultaneously, greatly increasing the negative consequences of extreme events,

g) **Self-reinforcing** – many elements of the Earth System react to warming by releasing greenhouse gases, further accelerating climate change (positive feedback),

h) **Irreversible** – feedbacks may cause the crossing of tipping points, with the potential to irreversibly change ecosystems and processes in the Earth system, including the possibility of cascading to an unimaginably hostile world.

3.1 Climate change is fundamental to the environment

41) Over the last million or so years, the Earth system has travelled on bounded **pathways that connect glacial periods to warmer interglacial periods.** These pathways are not identical, but cycle about every 100,000 years.[5] (See Fig. 2 below.)

[5] Steffen W et al. (2018) Trajectories of the Earth System in the Anthropocene. Proc. Natl. Acad. Sci. (USA) doi:10.1073/pnas.1810141115 and references therein https://www.pnas.org/content/pnas/115/33/8252.full.pdf

42) **The climate changes profoundly during each transition, reshaping the Earth's physical system and the life it supports.** Sea levels can change by 100 m, the fraction of the Earth's surface covered with ice dramatically changes, and different species dominate the biosphere, on land and in the ocean. Yet these **hugely different versions of Earth are separated by only 4 – 6°C of average global temperature**.

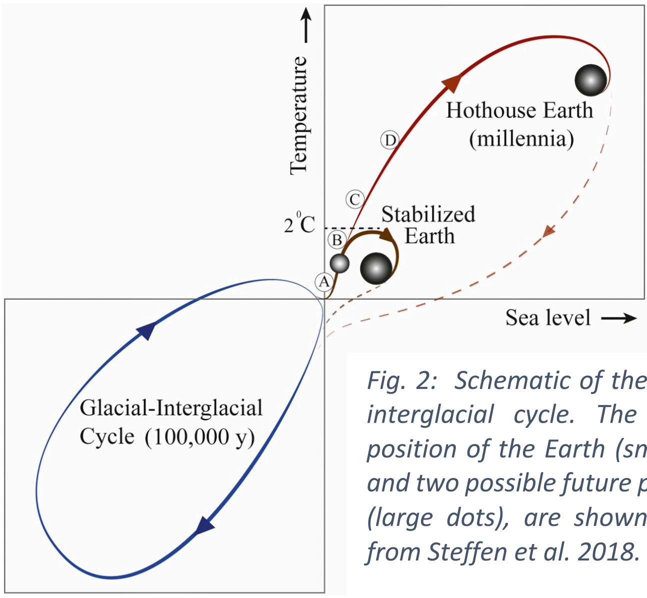

Fig. 2: Schematic of the glacial-interglacial cycle. The current position of the Earth (small dot) and two possible future positions (large dots), are shown. Figure from Steffen et al. 2018.

43) **Anthropogenic GHG emissions are now pushing the Earth System rapidly away from the glacial-interglacial cycle of stability** (see Fig. 2) **toward new, hotter climatic conditions and a profoundly different biosphere.**

3.2 Climate change is global

44) Due to the interconnectivity of the Earth's systems, **GHGs emitted anywhere are distributed throughout the atmosphere, where they contribute to the warming of the planet as a whole**. Thus, **the location, or the identity of the emitter, is of no consequence to the ultimate warming effect**. Australian emissions contribute to climate change impacts everywhere on Earth, and emissions from any location on Earth influence the effects that Australia experiences from climate change. **Humans bear collective responsibility for anthropogenic climate change.**

45) A very large number of small, individual human sources of greenhouse gases combine to form the collective global risk of climate change. **If every source of emissions that is a 'small fraction of the whole' were to be ignored, the problem would persist.**

3.3 Anthropogenic change is comprehensively dangerous

46) **Current levels of greenhouse gases are already dangerous**: ecosystems are degrading and catastrophes due to extreme weather are occurring that can be directly attributed to anthropogenic climate change. Recent IPCC reports[6,7,8] outline the comprehensive nature of the damage already being done by climate change across the whole of Earth's environmental systems, as well as that likely to occur in future if greenhouse gas emissions remain unchecked. Some of these effects are detailed in Section 6.2 of this Report. **Nearly every environmental system on Earth will be affected if global warming increases to 3°C – 4°C**.

3.4 Anthropogenic climate change is rapid

47) The dramatic changes that accompany the switch from a glacial to an interglacial period occur over tens of thousands of years with total temperature changes of about 5°C. **Yet in just 200 years humans have raised the average global temperature to more than 20% of this glacial-interglacial gap**, so that the Earth is now nearing the upper envelope of interglacial conditions over the past 1.2 million years.[9]

48) The speed of this change makes it difficult, or in some cases impossible, for species and ecosystems to adapt. A study of 105,000 species found that even at 1.5°C of warming, 6% of insects, 8% of plants, and 4% of vertebrates are likely to lose over half of their climatically determined geographical area; the percentages *double* for 2°C of warming.[10]

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[6] IPCC SR1.5 (2018) Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C. Accessed at: http://ipcc.ch/report/sr15/

[7] IPCC (2014): Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Field et al. (eds.) Cambridge University Press, pp. 1-32.

[8] 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, accessed at: https://www.ipcc.ch/report/ar6/wg2/

[9] Steffen W et al. (2018) Trajectories of the Earth System in the Anthropocene. *Proc. Natl. Acad. Sci. (USA)* doi:10.1073/pnas.1810141115 and references therein https://www.pnas.org/content/pnas/115/33/8252.full.pdf

[10] Warren, R., J. Price, E. Graham, N. Forstenhaeusler, and J. VanDerWal (2018): The projected effect on insects, vertebrates, and plants of limiting global warming to 1.5°C rather than 2°C. Science, 360(6390), 791–795, doi:10.1126/science.aar3646.

3.5 Climate change has delayed effects

49) **The full climatic effects of greenhouse gases (especially CO_2) are not felt until long after the time of emission** (see Section 4.1). This means that a few tenths of a degree of additional warming above the present 1.1°C – 1.2°C are already locked as inertia in the Earth system responds to greenhouse gases that have already been emitted.[11]

50) This, together with natural variability, means that **even with rapid reductions of about 5% per year (relative to the year previous) beginning in 2021, a drop in global average temperatures may not be reliably measured until about 2050**.[12] This is an example of how global emission decisions made in the period 1990 to 2020 have a delayed effect.

51) The amount of climate change expected in the next decade is similar under all plausible global emissions scenarios. However, by the mid-21st century, higher ongoing emissions of greenhouse gases will lead to greater warming and associated impacts, while reducing emissions will lead to less warming and fewer impacts.[13] **The lag between the full effects of emissions and the global warming they cause means that what we do this year has consequences for every year hereafter into the foreseeable future**.

3.6 Climate change is compounding

52) **The effects of climate change often compound one another**, acting to amplify deleterious effects. This includes instances where **multiple destructive events or elements occur at the same time or in close succession, exacerbating one another such that the overall impact is worse than if each had occurred in isolation.**[14,15]

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[11] IPCC SR1.5 (2018) Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C. See their Fig. 1.5. Accessed at: http://ipcc.ch/report/sr15/
[12] Samset, BH, Fuglestvedt, JS and Lund, MT (2020) Delayed emergence of a global temperature response after emission mitigation. *Nature Communications,* 11, 3261, https://doi.org/10.1038/s41467-020-17001-1 (and references therein)
[13] CSIRO/BOM (2020) State of the Climate 2020. http://www.bom.gov.au/state-of-the-climate/
[14] Steffen, W. and Bradshaw, S. (2021) Hitting Home: The Compounding Costs of Climate Inaction, and references cited therein. Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/hitting-home-compounding-costs-climate-inaction
[15] IPCC (2022) Summary for Policy Makers, in Climate Change 2022: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg2/

53) For example, tropical storms are damaging not only due to high winds, but also due to accompanying storm surge caused by rising sea levels and a warming, wetter atmosphere. This can then cause coastal erosion and flooding with different and longer lasting consequences.

54) Another example is the drivers of interannual climate variability over southeast Australia, which do not operate independently of each other. This increases the chance of compounding effects on fire risk.[16] Further, pre-existing drought conditions and heatwaves often occur simultaneously with high fire danger days. This 'triple whammy' effect has severe implications not only for the landscape and the ecosystems it supports, but also for humans working outside, on the land, and combating fires.

3.7 Climate change can be self-reinforcing

55) In some cases, the response of an Earth subsystem can enhance (or diminish) the effect of global warming itself. The physical, chemical and biological processes that cause these effects are called *feedbacks*.

56) ***Negative feedbacks* are those that act in the opposite sense of warming to restore Earth back to its original stability**. Examples include: the physics of (black body) radiation that increases the amount of outgoing radiation into space as the Earth warms, and the larger uptake of carbon by land forests and oceans as the Earth warms. Detailed climate models include these effects. Some negative feedback processes, such as the uptake of carbon by forests, are losing strength, increasing the **risk that self-reinforcing mechanisms will counter efforts to mitigate further climate change, and instead accelerate it**.[17,18]

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[16] Abram, N.J., et al. (2021) Connections of climate change and variability to large and extreme forest fires in southeast Australia, Communications Earth & Environment 2:8, https://doi.org/10.1038/s43247-020-00065-8

[17] Raupach MR, et al. (2014) The declining uptake rate of atmospheric CO2 by land and ocean sinks. Biogeosciences 11:3453–3475.

[18] WMO 2019, United in Science, Report prepared for the UN Climate Action Summit 2019, https://wedocs.unep.org/bitstream/handle/20.500.11822/30023/climsci.pdf

57) ***Positive feedbacks* are self-reinforcing mechanisms that act to enhance warming to push Earth away from its previous (cooler) stability state.** A few examples that are already underway include:[19]

a) dieback of the Amazon and Boreal forests due to global warming, which decreases their ability to act as carbon sinks, and releases their stored CO_2 into the atmosphere,

b) thawing of frozen permafrost soil due to warming, which releases CO_2 and/or CH_4, depending on local conditions,

c) reduced spring snow cover in the Northern Hemisphere and loss of summer sea-ice in the Antarctic and Arctic, and long-term loss of polar ice sheets, which reduces the amount of sunlight reflected back into space, as well as allowing land ice to more easily escape to the sea, increasing sea levels.

58) The combined effect of all climate feedback processes is net positive, that is, acting to amplify the climate response.[20]

3.8 Some climate changes are irreversible

59) According to the AR6 WGI, "**Many changes due to past and future greenhouse gas emissions are irreversible for centuries to millennia, especially changes in the ocean, ice sheets and global sea level."**[21] Specifically, the AR6 WGI lists the following:

a) Changes in global ocean temperature (*very high confidence*), deep ocean acidification (*very high confidence*) and deoxygenation (*medium confidence*) are irreversible on centennial to millennial time scales.

b) Mountain and polar glaciers are committed to continue melting for decades or centuries (*very high confidence*).

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[19] Steffen W et al. (2018) Trajectories of the Earth System in the Anthropocene. Proc. Natl. Acad. Sci. (USA) doi:10.1073/pnas.1810141115 and associated Appendix https://www.pnas.org/content/pnas/115/33/8252.full.pdf

[20] Arias, PA et al. (2021) Technical Summary Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg1/#FullReport

[21] 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, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

c) Loss of permafrost carbon following permafrost thaw is irreversible at centennial timescales (*high confidence*).

d) It is *virtually certain* that global mean sea level will continue to rise over the 21st Century. In the longer term, sea level is committed to rise for centuries to millennia due to continuing deep-ocean warming and ice-sheet melt, and will remain elevated for thousands of years (*high confidence*).

60) AR6 WGII details how **these irreversible effects in Earth's physical systems are already having irreversible impacts on Earth's biological, environmental and human systems, with more irreversible impacts expected, depending on the amount of further global warming.** Specifically, ARC WGII states that: [22]

a) Climate change has caused substantial damages, and increasingly irreversible losses, in terrestrial, freshwater and coastal and open ocean marine ecosystems (*high confidence*).

b) The extent and magnitude of climate change impacts are larger than estimated in previous assessments (*high confidence*).

c) Widespread deterioration of ecosystem structure and function, resilience and natural adaptive capacity, as well as shifts in seasonal timing have occurred due to climate change (*high confidence*), with adverse socioeconomic consequences (*high confidence*).

d) Approximately half of the species assessed globally have shifted polewards or, on land, also to higher elevations (*very high confidence*).

e) Hundreds of local losses of species have been driven by increases in the magnitude of heat extremes (*high confidence*), as well as mass mortality events on land and in the ocean (*very high confidence*) and loss of kelp forests (*high confidence*).

f) Some losses are already irreversible, such as the first species extinctions driven by climate change (*medium confidence*). Other impacts are approaching irreversibility,

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[22] IPCC (2022) Summary for Policy Makers, in Climate Change 2022: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg2/

such as the impacts of hydrological changes resulting from the retreat of glaciers, or the changes in some mountain (*medium confidence*) and Arctic ecosystems driven by permafrost thaw (*high confidence*).

3.9 Crossing climate tipping points could lead to a cascade to a `Hothouse Earth'

61) The **most devastating risk of continued global warming is that some of Earth's subsystems** (e.g., Arctic sea ice, ocean circulation, the Amazon rainforest, or coral reefs, for example) **will become unstable and `tip' irreversibly into new states that accelerate the effects of climate change**. Some of these subsystems are already showing signs of becoming unstable, with 'tipping points' that could lie on our current trajectory of global warming rising to 2°C, 3°C or 4°C above pre-industrial temperatures.[23,24]

62) *Tipping points*[25] in the Earth System refer to thresholds that, if crossed, would lead to far-reaching, and in some cases, abrupt and/or irreversible changes in subsystems (called tipping elements). **The nature of tipping points is that they are irreversible on timescales associated with natural variability in the Earth System**.

63) **Recent research indicates that tipping point risks are now much higher than earlier estimates**. Over **half of previously identified**[26] **tipping elements are now 'active,'** that is, they are moving in the direction that could cause irreversible change (see Fig. 3 below).[27]

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[23] Steffen W et al. (2018) Trajectories of the Earth System in the Anthropocene. Proc. Natl. Acad. Sci. (USA) doi:10.1073/pnas.1810141115 and associated Appendix, accessed at: https://www.pnas.org/content/pnas/115/33/8252.full.pdf

[24] Lenton, T. M., Rockström, J., Gaffney, O., Rahmstorf, S., Richardson, K, Steffen, W. & Schellnhuber, H.J. (2019) Nature, vol 575, pp 592 – 595.

[25] Schellnhuber HJ, Rahmstorf S, Winkelmann R (2016) Why the right climate target was agreed in Paris. *Nature Climate Change*, 6:649-653

[26] Lenton, T.M. et al. (2008) Tipping elements in the Earth's climate system. In PNAS, 105(6), p1786-1793. Accessed from: https://www.pnas.org/content/105/6/1786

[27] Lenton, T.M. et al. (2019) Climate tipping points — too risky to bet against. Nature, 2019; 575 (7784): 592. Accessed at: https://www.nature.com/articles/d41586-019-03595-0

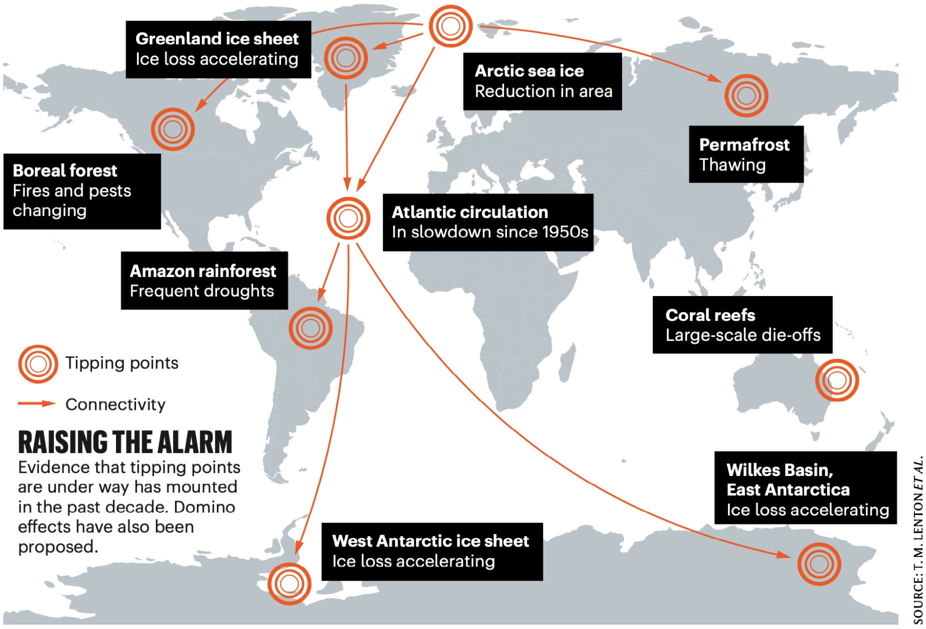

Fig. 3: Tipping elements that are currently changing, and their interactions with one another. (Figure from Lenton et al. 2019).

64) The recent AR6 WGI Report states: "**Abrupt responses and tipping points of the climate system, such as strongly increased Antarctic ice-sheet melt and forest dieback, cannot be ruled out (*high confidence*).**"[28]

65) **The Amazon rainforest**, historically a substantial carbon sink, is observed to have lost resilience to changes in climate and deforestation for the past 20 years, and **may now be headed toward a tipping point of permanent dieback that would accelerate warming**.[29]

66) **Permafrost peatlands in Europe and Western Siberia are very close to a (melting) tipping point that they will soon cross unless rapid and strong action is taken to reduce GHG emissions.**[30]

67) **One of the most significant tipping elements is the Atlantic Meridional Overturning Circulation (AMOC),**[31] a complex of deep and surface currents in the Atlantic Ocean that

[28] 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, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

[29] Boulton, C.A., Lenton, T.M. & Boers, T. (2022) Pronounced loss of Amazon rainforest resilience since the early 2000s, in Nature Climate Change, https://doi.org/10.1038/s41558-022-01287-8

[30] Fewster, R.E. et al. (2022) Imminent loss of climate space for permafrost peatlands in Europe and Western Siberia, in Nature Climate Change, https://www.nature.com/articles/s41558-022-01296-7

[31] NB: The Gulf Stream is part of AMOC.

is responsible for considerable heat exchange between the oceans and the atmosphere. **The AMOC appears to be at its weakest point (that is, the circulation and heat exchange responses are at their slowest) in the past 1000 years**.[32]

68) **Whilst there is *medium confidence* that there will not be an abrupt AMOC collapse before 2100, if such a collapse were to occur, it would *very likely* cause abrupt shifts in regional weather patterns and water cycle**, such as a southward shift in the tropical rain belt, weakening of the African and Asian monsoons and strengthening of Southern Hemisphere monsoons, and drying in Europe.[33]

69) **Continued warming increases the risk** that crossing tipping points will cause subsystems of the Earth to rapidly collapse, one initiating another, to create **a cascade of transformations that result in what has been dubbed a 'Hothouse Earth'.** [34] In this future, **average temperatures would rise to match those not seen since the beginning of the Stone Age, millions of years ago, with devastating consequences**. If such a cascade in a domino effect were to occur, the result would be an unrecognisable landscape for current ecosystems and human civilisation.

70) It is **uncertain precisely where this 'Hothouse' threshold may lie, but it could be as close as a few decades away, that is, at or just beyond 2°C of warming.**[35]

71) On the basis of the foregoing, it is reasonable to state that unabated climate change is the greatest threat to the environment and people of NSW.

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[32] Caesar, L., et al. (2021) Current Atlantic Meridional Overturning Circulation weakest in last millennium. Nat. Geosci. 14**,** 118–120 https://doi.org/10.1038/s41561-021-00699-z

[33] 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, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

[34] Steffen W et al. (2018) Trajectories of the Earth System in the Anthropocene. Proc. Natl. Acad. Sci. (USA) doi:10.1073/pnas.1810141115 and associated Appendix https://www.pnas.org/content/pnas/115/33/8252.full.pdf

[35] Steffen W et al. (2018) Trajectories of the Earth System in the Anthropocene. Proc. Natl. Acad. Sci. (USA) doi:10.1073/pnas.1810141115 and associated Appendix https://www.pnas.org/content/pnas/115/33/8252.full.pdf

4 Greenhouse Gas Emissions and Climate Change

72) This section is a brief review of greenhouse gases (GHGs) and their role in human-induced climate change.

4.1 Increases in greenhouse gases drive global warming

73) GHGs trap energy that would otherwise escape from the Earth's upper atmosphere; they have kept the Earth's surface at temperatures suitable for modern human civilisation and agriculture for thousands of years.

74) Since industrialisation, however, and in particular over the last 70 years, **human activities have upset this long-standing balance, by increasing the amount of GHGs in the atmosphere.** The additional GHGs caused by human activity create an energy imbalance. **Extra energy is returned to the Earth's surface, causing the global warming that fuels changes in the global climate.**

75) The primary GHGs driving current human-caused climate change are **carbon dioxide (CO_2)**, **methane (CH_4)**, and **nitrous oxide (N_2O)**. These gases differ in their concentration in the atmosphere, residence time in the atmosphere, and potential to cause a given amount of warming per weight. Of these, **atmospheric concentration is the only property of GHGs that can be significantly influenced by humans**.

76) Excess amounts of CH_4 and N_2O persist in the atmosphere for about 12 and 109 years, respectively.[36] The life cycle of atmospheric CO_2 is more complex. **Most of the carbon dioxide that is not absorbed quickly by ocean and land 'sinks' will remain in the atmosphere for thousands of years or longer.**[37] This is the primary reason why **most long term global warming is caused by increases in the amount of CO_2 in the atmosphere**.

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[36] Forster P., T. et al. (2021) The Earth's energy budget, climate feedbacks, and climate sensitivity, Chapter & of Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Table 7.15, accessed at: https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/

[37] Lee, J.Y. et al. (2021) Future Global Climate: Scenario-Based Projections and Near-Term Information, Chapter 4 of Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/

77) Due to their different chemical properties and residency times in the atmosphere, GHGs have different global warming potentials (GWPs), that is, per kilogram they differ in the amount of heat they trap over a given period of time after they are emitted. **Over a 20-year period, fossil methane[38] is 82.5 times more effective than CO_2 in trapping heat, and 29.8 times more effective over 100 years. Nitrous oxide has a global warming potential about 273 times that of CO_2 on timescales of 20 to 100 years**.[39]

78) Whilst GHGs remain in the atmosphere, they continue to contribute to global warming, year after year, regardless of when they were emitted. This means that **the full effect of past GHG emissions is yet to be felt**, as the Earth continues to warm under the influence of historical emissions (particularly CO_2) as well as those emitted in the current year.

79) **Atmospheric concentrations of CO_2, CH_4 and N_2O have risen since the industrial revolution, with dramatic upward increases of CO_2 beginning around 1960** (Fig. 4).[40]

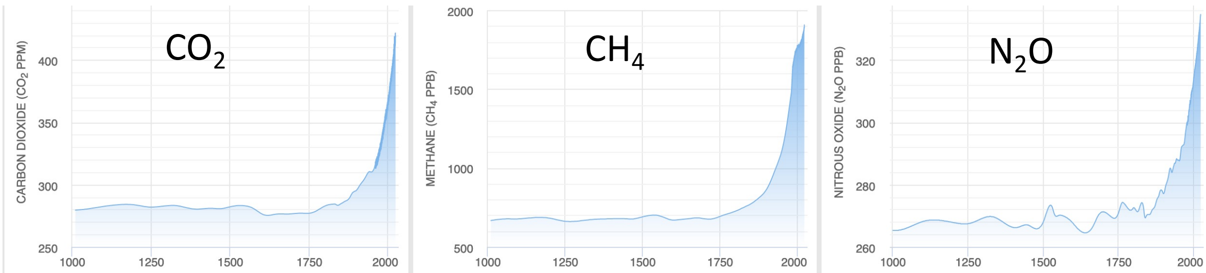

Fig. 4: The rise of GHGs in the atmosphere from 1000AD to present. Graph prepared by the Two Degree Institute, based on ice core records (CSIRO) and in situ measurements (Scripps).

80) Current levels of CO_2, CH_4 and N_2O in the atmosphere are about 147%, 256% and 123%, respectively, of their pre-industrial levels around 1750.[41]

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[38] Note: Fossil methane has a higher GWP than other sources of CH_4 because it results in fossil carbon added to the atmosphere, which was not previously part of the carbon cycle of the atmosphere. The GWPs for *non-fossil* CH_4 is 80.8 and 27.2 on 20 and 100-year timescales, respectively.

[39] Forster P., T. et al. (2021) The Earth's energy budget, climate feedbacks, and climate sensitivity, Chapter 7 of Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Table 7.15, accessed at: https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/

[40] 2 Degrees Institute (2020) Accessed at: https://www.climatelevels.org/

[41] 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, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

81) **The rate at which atmospheric concentrations of the main GHGs is increasing is *itself* increasing**, as illustrated in Fig. 5 at right.[42]

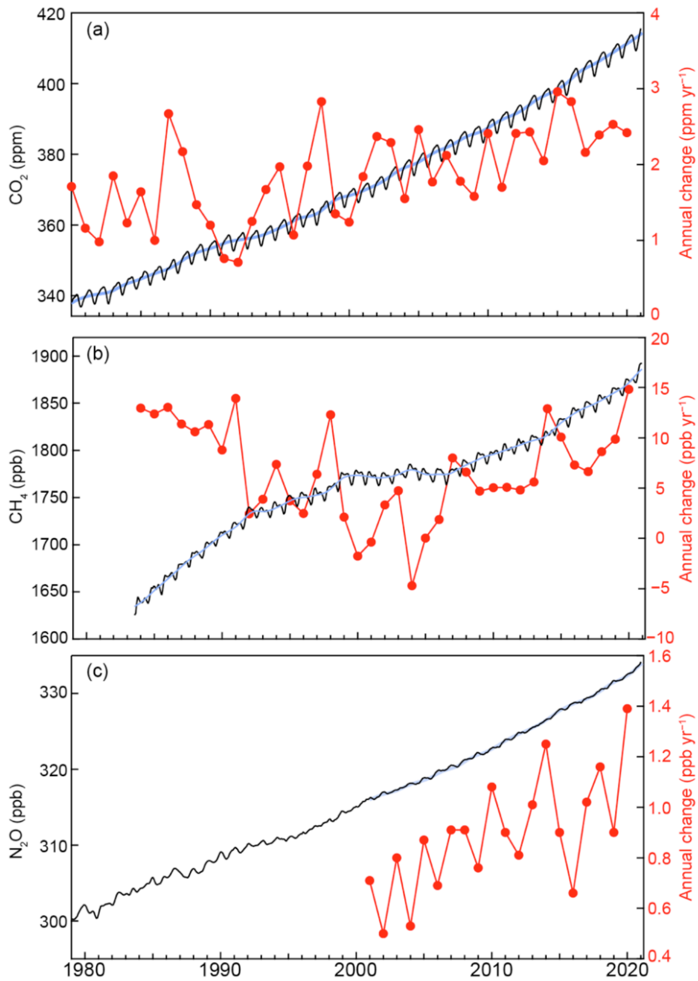

Fig. 5: Dark lines: Increases in the atmospheric concentration of CO_2, CH_4 and N_2O from 1980 to 2020. Note that the vertical scales do not start at zero. Red lines: Increases in each year compared to the previous year. This figure derives from Figure 2.50 of Blunden and Boyer (2020).

82) The **current level of atmospheric CO_2 is** about 415 parts per million (ppm), **25% higher than any other time since the mid-Pliocene, about 2 million years ago,**[43] and **concentrations of CH_4 and N_2O are higher than at any time in at least 800,000 year**s.[44] See Fig. 6 below.

[42] Blunden, J. and T. Boyer, eds. (2020) State of the Climate in 2020 in *Bull. Amer. Meteor. Soc.*, 102 (8), Si–S475, https://doi.org/10.1175/2021BAMSStateoftheClimate.1

[43] Fedorov, A.V. et al (2013) Patterns and mechanisms of early Pliocene warmth, in Nature, 496, doi:10.1038/nature12003.

[44] 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, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

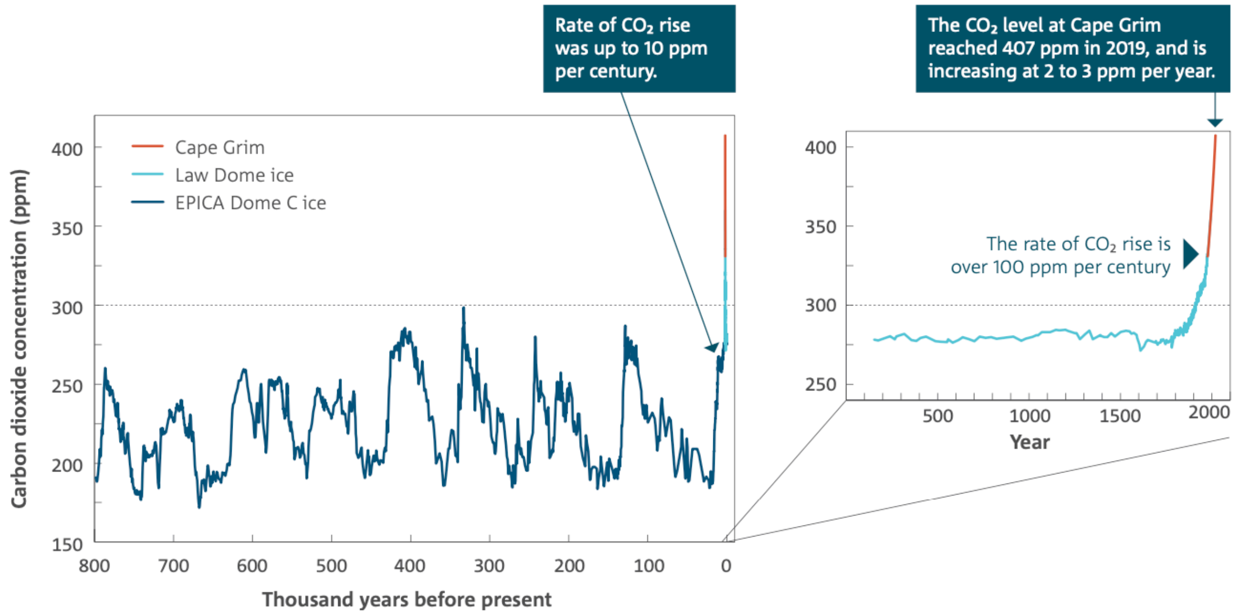

Fig. 6: Current increases in atmospheric CO_2 compared to last 800,000 years. Figure from CSIRO/BOM (2020).

83) For perspective, the species *Homo sapiens* (modern human) is thought to have arisen only 300,000 to 600,000 years ago. In other words, **carbon dioxide levels are higher now than at any other time our species has inhabited the Earth**. (See Fig. 6 above.)[45]

84) **Since 1970, the global average surface temperature has been rising at a rate** of 2.0°C per century,[46,47] **about 200 times faster than the average rate of change** of about 0.01°C per century **for the last 7,000 years**.[48]

4.2 Individual extreme events can be linked directly to global warming

85) All extreme weather events, in fact, **all weather events are affected by climate change**, because the environment in which they occur is warmer, moister and contains more energy than used to be the case.[49] The field of **attribution science is now allowing**

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[45] CSIRO/BOM (2020), State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate

[46] NOAA (2016) State of the Climate: Global Analysis for Annual 2015. National Centers for Environmental Information, available at http://www.ncdc.noaa.gov/sotc/global/201513

[47] IPCC SR1.5 (2018) Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C. Accessed at: http://ipcc.ch/report/sr15/

[48] Marcott SA, Shakun JD, Clark PU, Mix A (2013) A reconstruction of regional and global temperature for the past 11,300 years. *Science* 339:1198-1201

[49] Trenberth, K. E. (2012), Framing the way to relate climate extremes to climate change, Climate Change, 115(2), 283–290, doi:10.1007/s10584-012-0441-5

scientists to quantity the effect of climate change on many extreme events and the consequences of anthropogenic climate change more generally. Just a few examples are listed below.

86) Of the 131 studies investigating whether climate change is influencing extreme weather published in the Bulletin of the American Meteorological Society between 2011 and 2016, **65 percent found that the probability of the event occurring was increased due to anthropogenic climate change**. **In the case of some extreme high temperatures, the probability increased by a factor of ten or more**.[50]

87) **The widespread coral bleaching of the Great Barrier Reef during 2016 was made 175 times more likely due to climate change**.[51]

88) **Hurricane Harvey** caused deaths, extreme rainfall, catastrophic flooding and economic losses estimated at 215 billion in 2017 USD. Attribution studies have found that the amount of **rainfall** associated with the hurricane system **was increased three-fold by human-induced climate change**.[52]

89) According to the United Kingdom (UK) Met Office,[53] **human-induced climate change has made the 2018 record-breaking UK summer temperatures about 30 times more likely** than they would naturally occur.

90) The **2020 Siberian heatwave would have been "almost impossible" without human-induced climate change**, as it was made at least 600 times more likely as a result of human-induced climate change.[54]

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[50] WMO (2018) July sees extreme weather with high impacts. Accessed at: https://public.wmo.int/en/media/news/july-sees-extreme-weather-high-impacts

[51] King A, Karoly D, Black M, Hoegh-Guldberg O, and Perkins-Kirkpatrick S (2016) Great Barrier Reef bleaching would be almost impossible without climate change. The Conversation, April 29, 2016.

[52] IPCC (2022) Chapter 4, Water, in Climate Change 2022: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg2/

[53] UK Met Office (2018) 2018 UK summer heatwave made thirty times more likely due to climate change. Accessed at https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2018/2018-uk-summer-heatwave

[54] Ciavarella, A. et al. (2020) Prolonged Siberian Heat of 2020. *World Weather Attribution.* https://www.worldweatherattribution.org/siberian-heatwave-of-2020-almost-impossible-without-climate-change

91) **The 2019-2020 Australian bushfires were made 30 – 80% more likely due to anthropogenic climate change**.[55]

92) A recent meta-analysis[56] of 27 studies concerning a total of 976 species found that **47% of local extinctions reported across the globe during last century could be attributed to climate change**.

93) **Of more than 4,000 species** examined in studies that assessed attribution, about **half had shifted their geographical locations** poleward or to higher altitude **due to human-induced climate change**.[57]

94) In the period 1991–2018, **37% of warm-season, heat-related human deaths have been attributed to anthropogenic climate change**.[58]

95) Based on observations and modelling, the **heatwave in the Pacific Northwest of Canada and the US** has been found to be **"virtually impossible" without human-caused climate change**; climate change made the event about 150 times more likely.[59]

4.3 Humans are the cause of essentially all currently observed global warming

96) ***Anthropogenic* climate change is change in the Earth's climate caused by *human activities* that release additional greenhouse gases (GHGs) into the atmosphere or alter the natural land and ocean sinks for these gases**.

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[55] Oldenborgh, G.J. et al. (2021) Attribution of the Australian bushfire risk to anthropogenic climate change, Natural Hazards and Earth System Sciences, 21, 941. Accessed at: https://doi.org/10.5194/nhess-21-941-2021
[56] Wiens, J.J., 2016: Climate-Related Local Extinctions Are Already Widespread among Plant and Animal Species. PLOS Biology, 14(12), e2001104, doi:10.1371/journal.pbio.2001104.
[57] IPCC (2022) Chapter 2, Terrestrial and Freshwater Ecosystems and their Services, in Climate Change 2022: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg2/
[58] Vicedo-Cabrera, A.M. et al. (2021) The burden of heat-related mortality attributable to recent human-induced climate change. Nature Climate Change, 11, 492-500. Accessed at: https://www.nature.com/articles/s41558-021-01058-x
[59] Phillip, S.Y. et al. (2021) Rapid attribution analysis of the extraordinary heatwave on the Pacific Coast of the US and Canada June 2021, Earth System Dynamics, Accessed at: https://esd.copernicus.org/preprints/esd-2021-90/

97) **Nearly all of the warming experienced in past 160 years is due to human activities**, with natural forces (volcanos, changes in solar radiation, etc) playing a negligible role.[60]

98) The AR6 WGI [61] makes clear the direct relationship between humans and the global warming driving climate change (my emphasis):

a) "It is **unequivocal that human influence has warmed the atmosphere, ocean and land**" and

b) "**Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years**" and

c) "**Observed warming is driven by emissions from human activities**, with greenhouse gas warming partly masked by aerosol cooling."

99) **Reducing net anthropogenic GHG emissions to zero and maintaining them at that level is the only way that humans can stabilise the climate. The primary determinant of future climate change, beyond that which is already locked in by emissions to date, is the future trajectory of world emissions, especially the path between now and 2030**.[62] The more quickly emissions are brought and held to zero, the lower the peak global warming temperature will be.

4.4 Human greenhouse gas emissions come primarily from fossil fuels

100) **At present, about 90% of the additional CO_2 emitted per year is from the burning of coal, gas, and oil**,[63] with most of the remainder due to land use changes (e.g., deforestation which removes a natural sink for CO_2).

[60] Gillett, N.P. et al. (2021) Constraining human contributions to observed warming since the pre-industrial period, in Nature Climate Change, https://doi.org/10.1038/s41558-020-00965-9

[61] 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, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

[62] WMO (2019) United in Science, Report prepared for the UN Climate Action Summit 2019, https://wedocs.unep.org/bitstream/handle/20.500.11822/30023/climsci.pdf

[63] Friedlingstein, P et al. (2021) Global Carbon Budget 2021, Earth Syst. Sci. Data. See their Table 6, https://essd.copernicus.org/preprints/essd-2021-386/

101) **Human CO_2 emissions from fossil fuel use continue to rise,** although at a smaller rate than in the first decade of this century.[64] (See Fig. 7.)[65]

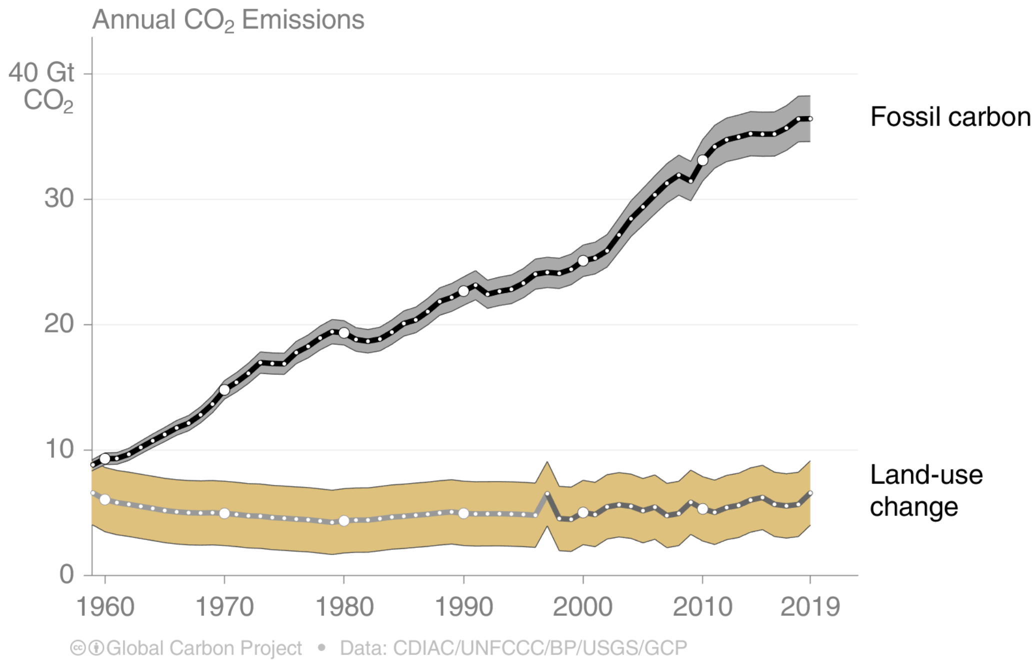

Fig. 7: Global human emissions from fossil sources continue to grow, whilst those from land-use changes (primarily deforestation) have remained relatively constant. Combined, humans emitted about 42 billion tonnes (Gt) of CO_2 into the atmosphere in 2019. Data from Friedlingstein et al (2020).

102) The growing trend in emissions continues: **year-on-year CO_2 emissions from fossil fuels are now more than 300% of 1960s levels.**[66]

103) The production, delivery and combustion of **fossil fuels is also associated with the release of CH_4.**[67] **A recent surge in atmospheric methane over the past decade is attributed in equal parts to agriculture (particularly livestock) and fossil fuels.**[68]

[64] Friedlingstein, P et al. (2020) Global Carbon Budget 2020, Earth Syst. Sci. Data, 12, 3269-3340. https://doi.org/10.5194/essd-12-3269-2020
[65] Figure is from the Global Carbon Project (2020), Accessed at : https://www.globalcarbonproject.org/carbonbudget/20/presentation.htm
[66] Friedlingstein, P et al. (2019) Global Carbon Budget 2019, Earth Syst. Sci. Data, 11, 1783–1838, See their Table 6, https://doi.org/10.5194/essd-11-1783-2019
[67] WMO 2019, United in Science, Report prepared for the UN Climate Action Summit 2019, https://wedocs.unep.org/bitstream/handle/20.500.11822/30023/climsci.pdf
[68] Jackson, RB et al. (2020) Increasing anthropogenic methane emissions arise equally from agricultural and fossil fuel sources, Environ. Res. Lett., 15, 071002, https://doi.org/10.1088/1748-9326/ab9ed2

5 Greenhouse Gas Emissions from the Dendrobium SSI Project

104) In this section, the expected Project GHG emissions are set out as presented in the Project's Environmental Impact Statement[69] (the EIS), and with alternate assumptions.

105) According to the Project's EIS:

a) The Dendrobium Mine in the Illawarra Region of NSW is an existing underground mine that began operating in 2002 and primarily produces metallurgical coal for steelmaking. **The approved Dendrobium Mine has development consent until 2030, with approved operational capacity of up to 5.2 million tonnes per annum (Mtpa) of Run of Mine (ROM) coal.**

b) The proposed Project involves continuation of mining activities at the Dendrobium Mine with a new underground mining area (Area 5) within the existing mining lease, including the use of existing infrastructure and development of minimal additional surface infrastructure.

c) Specifically, the Project includes the continuation of longwall mining at the approved Dendrobium Mine within a **new underground mining area (Area 5) to extract approximately 31 million tonnes (Mt) ROM coal**.

d) Development **consent is sought to extract up to 5.2 Mtpa of ROM coal, through underground mining operations within Area 5 until approximately 31 December 2034, and to extend the life of the Dendrobium Mine until 31 December 2041**.

5.1 Indicative Mining and Coal Washing Schedules

106) Indicative mining and coal wash schedules related to the Project appear as Table 4-3 and Table 4-4 of Section 4[70] of the EIS, respectively. These two tables are reproduced in Fig. 8 of this Report (below), for ease of comparison.

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[69] South 32 (2022) Dendrobium Mine Extension Project Environmental Impact Statement (EIS) https://www.planningportal.nsw.gov.au/major-projects/projects/dendrobium-mine-extension-project-0

[70] EIS Section 4: Project Description. https://www.planningportal.nsw.gov.au/major-projects/projects/dendrobium-mine-extension-project-0

Indicative Mining Schedule

Project Year	ROM Coal Production (Mt)		ROM Coal Handling and Processing (Mt)		
	Approved Dendrobium Mine Mining (Area 3) (DA 60-03-2001)*	Project Underground Mining Area (Area 5)	Total ROM Coal	Coal Wash (Wet)	Total Product Coal
1	3.9	-	3.9	0.9	3.1
2	4.3	-	4.3	1.0	3.4
3	3.6	0.1	3.6	0.9	2.8
4	3.1	0.2	3.3	0.9	2.6
5	2.4	0.4	2.8	0.7	2.2
6	-	1.3	1.3	0.2	1.1
7	-	3.2	3.2	0.5	2.8
8	-	4.6	4.6	0.7	4.0
9	-	5.2	5.2	0.8	4.5
10	-	4.7	4.7	0.8	4.1
11	-	4.7	4.7	0.8	4.1
12	0.2	3.4	3.6	0.7	3.0
13	0.3	3.5	3.8	0.6	3.3
14	3.3	-	3.3	0.9	2.5
15	3.4	-	3.4	0.9	2.5
16	3.3	-	3.3	0.9	2.5
17	3.1	-	3.1	0.9	2.2
18	2.9	-	2.9	1.0	2.1

Note: The combined total of product coal and coal wash is greater than total ROM coal due to changes in moisture content. Other totals may not add exactly due to rounding. Forecast production tonnages cannot be accurately split into market segments, as product coal is blended with coal from the Appin Mine to meet customer specifications, and sold as a single IMC product. In addition, this information is considered commercial in confidence (as recognised by the MEG in its advice to the SEARs). IMC can provide this information commercial in confidence to DPE if requested.

* ROM coal extraction in Area 3 would continue to be conducted in accordance with Development Consent DA 60-03-2001.

Indicative Production Schedule of Coal Wash to be Emplaced at the West Cliff Coal Wash Emplacement Area and/or Available to be Supplied for Beneficial Use

Year	Coal Wash Production from Dendrobium Mine and Project Processing Activities (Mt)*	Approved Appin Mine Coal Wash Production (Mt)#	Total Coal Wash Production (Mt)
1	0.9	1.0	1.9
2	1.0	0.8	1.8
3	0.9	0.8	1.7
4	0.9	0.8	1.7
5	0.7	1.0	1.7
6	0.2	1.0	1.3
7	0.5	0.9	1.4
8	0.7	1.0	1.8
9	0.8	1.0	1.8
10	0.8	1.0	1.7
11	0.8	1.0	1.8
12	0.7	1.0	1.7
13	0.6	0.9	1.6
14	0.9	1.0	1.9
15	0.9	1.0	1.9
16	0.9	1.0	1.9
17	0.9	0.5	1.4
18	1.0	-	1.0
TOTAL	**14.2**	**15.8**	**29.9**

Note: Totals may not add exactly due to rounding.

* Includes coal wash generated from processing of ROM coal from the approved Dendrobium Mine (Area 3) mining areas and Project underground mining area (Area 5).

\# Approximation based on current mine scheduling. This would continue to occur under Project Approval 08_0150.

Fig. 8. Indicative mining and coal wash schedules. From Tables 4-3 and 4-4 of Section 4 of the EIS.

107) Year 1 in the indicative mining and coal wash schedules (Fig. 8) represents the year of putative approval, which I assume for the purposes of this Report to be 2022. In that case, Year 13 would be calendar year 2034, the last year for which approval of mining at Area 5 is sought. Nevertheless, both schedules continue to Year 18, that is, through year 2039.

108) Table notes from the EIS (and reproduced in Fig. 8 above) indicate that the coal in those additional five years (Years 14 – 18 inclusive) would come from Area 3, under Development Consent 60-03-2001. However, that Consent is only valid (with amendments) to 31 December 2030. Coal washing activities are indicated both for coal mined from Area 3 and from coal from the Appin Mine; the latter acts under Project Approval 08_0150, which is valid until 31 December 2041.

109) Thus, **requesting an extension of the life of the Dendrobium Mine to 2041 as part of this SSI Project, rather than through 2034 (which is relevant for the Area 5 request) appears to be an anticipation by the Applicant that additional Dendrobium coal may be mined *outside* Area 5 in the years after 2030.** Such an anticipation is noted in Section 1 of the EIS and is consistent with listing coal mined from Area 3 in the indicative mining schedule in years 2035 – 2039, even though no consent has been granted (or is requested in the Project) for that to occur[71]. Indeed, some (but not the largest sources of) GHG emissions related to this post-2030 Area 3 coal are included in the Applicant's estimates of GHG emissions for the Project (see paragraph 116).

5.2 Environmental Impact Statement Estimates of Project Greenhouse Gas Emissions

110) **The GHG estimates for the Project used in the EIS have been prepared by Ramboll (hereafter EIS GHG Estimates), and are included as Appendix I of the EIS.**[72] **The EIS GHG Estimates are based on the indicative mining and coal wash schedules reproduced in Fig. 8 of this Report**.

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[71] EIS Section 1: Introduction, which states "*the necessary extension to the operational life of the Dendrobium Mine under Development Consent DA 60-03-2001 to allow mining in the majority of Area 3C [. . .] after 31 December 2030 would be subject to a separate application for approval and is not part of this application.*"

[72] EIS Appendix I: Air Quality and Greenhouse Gas Assessment (15 March 2022). https://www.planningportal.nsw.gov.au/major-projects/projects/dendrobium-mine-extension-project-0

111) For geographical reporting purposes, GHGs are often accounted in one of three *Scopes*,[73] as follows:

a) **Scope 1**: Emissions released to the atmosphere as a direct result of an activity, or series of activities at a facility level. Sometimes referred to as direct emissions.

b) **Scope 2**: Emissions released to the atmosphere from the indirect consumption of an energy commodity.

c) **Scope 3**: Indirect greenhouse gas emissions other than Scope 2 emissions that are generated in the wider economy as a consequence of the activities of a facility, but from sources not owned or controlled by that facility's business.

112) The EIS GHG Estimates are tabulated into these three scopes for Years 1 through 18 in Tables 8-6 and 8-7 of EIS Appendix I, and then summarised in Table 8-8 of that document. That summary is reproduced below as Fig. 9 (below) of this Report.

Project Year	Approved Mine Mt	Project Underground Mining - Area 5 (ROM Mt)	Scope 1	Scope 2	Scope 3
1	3.9	0.0	132,542	70,192	30,533
2	4.3	0.0	146,590	78,191	33,727
3	3.6	0.1	239,156	65,088	161,582
4	3.1	0.2	350,397	60,052	553,679
5	2.4	0.4	335,353	51,362	1,010,420
6	0.0	1.3	439,449	23,775	3,116,670
7	0.0	3.2	884,140	57,878	7,721,715
8	0.0	4.6	1,095,496	83,490	11,207,754
9	0.0	5.2	1,151,701	93,256	12,529,034
10	0.0	4.7	1,123,937	85,026	11,373,356
11	0.0	4.7	1,184,539	85,361	11,336,292
12	0.2	3.4	1,090,745	64,955	8,231,020
13	0.3	3.5	1,030,684	68,135	8,410,240
14	3.3	-	356,810	58,932	24,425
15	3.4	-	359,051	60,661	24,900
16	3.3	-	357,535	60,305	24,517
17	3.1	-	345,805	55,331	21,720
18	2.9	-	337,985	53,111	19,772
Max annual			**1,453,818**	**93,256**	**12,473,782**
Average annual			**789,551**	**65,283**	**4,183,740**
LOM total			**10,961,913**	**1,175,101**	**75,307,326**

Fig. 9. EIS GHG Estimates as taken directly from summary Table 8-8 of Appendix I of the EIS. All amounts are given in tonnes of CO_2-e. The values highlighted in light gold appear to be incorrect summary statistics for their respective columns.

113) It is beyond the scope of this Report to review the detailed methodology and individual sources of emissions estimated in the EIS GHG Estimates for each Scope and year. However, **I would like to point out several inconsistencies in the EIS summary table** (see

[73] E.g., see Australian Clean Energy Regulatory (2018) Greenhouse gases and energy, http://www.cleanenergyregulator.gov.au/NGER/About-the-National-Greenhouse-and-Energy-Reporting-scheme/Greenhouse-gases-and-energy

Fig. 9). **The EIS Appendix I summary statistics from its Table 8-8**, which I have highlighted in light gold in Fig. 6, *do not* represent the maximum annual, average annual and life-of-the-mine (LOM) for the Scope 1 and Scope 3 columns, as is easy to verify.

114) Rather than speculate on why these inconsistencies occur, **for the purposes of this Report, I consider the EIS GHG Estimates to be the individual numbers given for each Scope in each of Years 1 through 18**, rather than rely on the inconsistent summary numbers at the bottom of Table 8-8 of EIS Appendix I. **The correct statistics, taking the EIS values listed by year at face value, are given in Table 2 of this Report.**

Table 2: Consistent Summary Statistics for EIS GHG Estimates, all in tonnes CO_2-e

	Scope 1	Scope 2	Scope 3
Maximum annual	1,184,539	93,256	12,529,034
Average annual	608,995	65,283	4,212,853
Life of the Mine Total	10,961,915	1,175,101	75,831,356

Table 2 Notes: The summary statistics in this table are consistent with the yearly values given in Table 8-8 of EIS Appendix I. Summary statistics in the EIS are inconsistent.

115) With the caveats given in paragraphs 113) and 114), I summarise in Table 3 below the EIS GHG Estimates for all three Scopes for three different time periods relevant to points discussion in this Report, namely: 2022–2030 inclusive; 2022–2034 inclusive; and 2022–2041, inclusive. Year 1 is taken to be 2022. Note that the emissions are now given in millions of tonnes (Mt) of CO_2-e to three decimal places for ease of reading.

Table 3: Estimated GHG emissions from the Project, as given in the EIS

Category of Emissions (Mt CO_2-e)	2022 – 2030 inclusive	Requested Area 5 Lifetime 2022 – 2034 inclusive	Assumed Lifetime of Mine 2022 – 2041 inclusive
Scope 1 (with flaring)	4.775	9.205	10.962
Scope 2	0.583	0.887	1.175
Scope 3	36.365	75.716	75.831
All Scopes	**41.723**	**85.808**	**87.968**

Table 3 Notes: Numbers are given to three decimal places (in Mt CO_2-e) and are for periods inclusive of the indicated beginning and ending years. See text for assumptions.

5.3 Alternate Estimates of Greenhouse Gas Emissions from the Project

116) **Three substantial points** that should be borne in mind **about the EIS GHG Estimates**, as given in Table 8-8 of Appendix I are:

a) The EIS GHG Estimates ***assume* flaring of pre- and post- gas drainage**, that is, that gases are combusted (flared) rather than released directly. According to EIS Appendix I, this results in fugitive emissions during operations (Scope 1) being reduced by 31%. **It is unclear to what extent flaring will be undertaken in the Project.** The EIS states that "*Gas would be flared or, if the gas is too low in methane content for flaring (or for other operational reasons), vented to the atmosphere.*"[74]

b) Post-mining, some fugitive gas will continue to escape the Project mining Area 5. Table 8-6 of EIS Appendix I **uses an estimate of 250,000 t CO_2-e annually for post-mining fugitives, but only for Years 14 – 18, whereas in principle, these emissions will continue indefinitely.**

c) **Mining beyond 2030 (Years 12 – 18) from Area 3 appears in the EIS indicative mining and coal wash schedules, as well as GHG tables in EIS Appendix I, despite no current approval for mining Area 3 beyond 31 December 2030**. **Included** in Tables 8-6 and 8-7 of EIS Appendix I **are GHG emissions associated with processing this post-2030 Area 3 coal**, such as washing and drying, **and transporting it, including to markets at or via Port Kembla. Yet no entries are made for the largest sources of GHG emissions from this putative coal**, namely **fugitive emissions** (Scope 1) and **emissions from end-use** (Scope 3). If the Project is approved as submitted (together with a required extension of the current mining activity in Area 3 to 2040) GHG emissions would be substantially larger than given in the Project EIS, due to those associated with mining fugitives and end-use combustion of the planned post-2030 Area 3 coal.

117) Consequently, for this Report **I have made alternate GHG estimates that in turn**:

a) **Consider a case in which no (or very little) flaring is undertaken for Area 5**. This is done using the vented, rather than flared values from Table 8-6 in EIS Appendix I. Only Scope 1 emissions are affected.

b) **Extend post-mining fugitive emissions for Area 5 to at least 2050**. This is done by applying the annual Area 5 post-mining fugitive estimate of 250,000 t CO_2-e used in

[74] EIS Executive Summary, p. ES 27 https://www.planningportal.nsw.gov.au/major-projects/projects/dendrobium-mine-extension-project-0

the EIS GHG Estimates for years beyond Year 18 and up to and including 2050. Only Scope 1 emissions are affected.

c) **Include operational fugitive emissions (on the assumption they are not flared) and end-use emissions for post-2030 coal mined from Area 3.** Scope 1 and Scope 3 emissions are affected. According to EIS Indicative Mining Schedules this post-2030 Area 3 coal mining is intended, and is a primary justification for extending the life of the Dendrobium Mine to 2041. I use the indicative mining schedule in the EIS to obtain the anticipated ROM and Product coal in each post-2030 year. Then, I estimate fugitive emissions from this additional Area 3 mined coal by applying the average per ROM values estimated for Area 5 over the primary production years of its putative operation (Years 6 – 13).[75] Scope 3 end-use emissions for post-2030 Area 3 coal are estimated using the factor 2.766 Mt CO_2-e/Mt Product coal derived from Area 5 over those years.

118) Results of this analysis are shown in Table 4 below, over the same time periods as set out in Table 3. Table 4 indicates possible GHG emissions *in addition* to those in Table 3. In principle, **all these cases could eventuate, leading to possible totals of 21.588 Mt CO_2-e in Scope 1 emissions and 121.815 Mt CO_2-e in Scope 3 emissions over the life of the mine.** The impact of GHG estimates for the Project are considered in Section 8.

Table 4: Alternate estimates from this Report for *additional* Project GHG emissions under different assumptions than used in the EIS

Category of Additional Emissions (Mt CO_2-e)	2022 – 2030 inclusive	Requested Area 5 Lifetime 2022 – 2034 inclusive	Assumed Lifetime of Mine 2022 – 2041 inclusive
+ Scope 1 from Area 5 if no flaring	1.488	3.314	3.314
+ Scope 1 from post-mining Area 5 fugitives	–	–	1.750
+ Scope 1 from post-2030 Area 3 coal (no flaring)	–	0.172	5.662
+ Scope 3 from Area 3 post-2030 coal	–	1.209	33.847

Table 4 Notes: Numbers are given three decimal places (in Mt CO_2-e) and are for periods inclusive of the indicated beginning and ending years. See text for assumptions.

[75] Using entries from Tables 8-6 and 8-7 of EIS Appendix I, this value is 0.343 Mt CO2-e/Mt ROM, for unflared fugitive emissions. It is acknowledged that these emissions per tonne may differ somewhat between Area 3 and Area 5 due to differences in the gassiness.

6 Current Climate Impacts and Possible Climate Change Futures

119) This section describes some of the current and expected future impacts of climate change for the globe, Australia, and NSW in particular. **Future climate impacts depend most critically on fossil fuel emissions in the two decades over which the Applicant is requesting that the life of the Dendrobium Mine be extended.**

6.1 Current Impacts

120) Average global warming is currently about 1.1°C – 1.2°C above pre-industrial levels. This subsection briefly describes some resulting impacts at this level of warming.

6.1.1 Global

121) Growing GHG concentrations in the atmosphere cause an imbalance in the amount of energy absorbed by the Earth and the amount emitted into space. This imbalance has been growing rapidly. **The Earth's energy imbalance is estimated in mid-2019 to be about 2 to 3 times what it was in mid-2005**.[76]

122) Most of this additional energy is absorbed by Earth's oceans, especially in the upper 700m but also as deep as 2km. The rise is dramatic since 1990 (See Fig. 10).

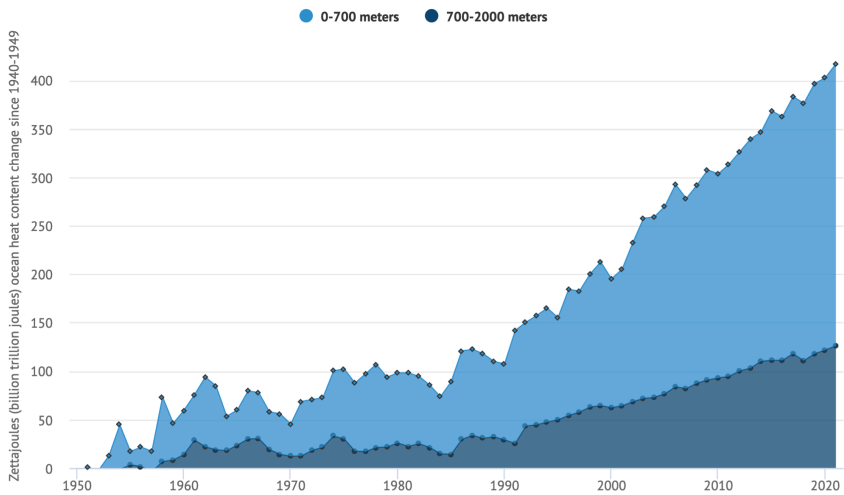

Fig. 10: Annual global ocean heat content (in zettajoules – billion trillion joules, or 10^{21} joules) for layers 0-700 metres (medium blue) and 700-2000 metres (dark blue) beneath the surface. Chart is taken from Carbon Brief (https://www.carbonbrief.org/state-of-the-climate-how-the-world-warmed-in-2021/) based on data from Cheng, et al. 2022, Advanced in Atmospheric Sciences, 39,

[76] Loeb, N. G., Johnson, G. C., Thorsen, T. J., Lyman, J. M., Rose, F. G., & Kato, S. (2021). Satellite and ocean data reveal marked increase in Earth's heating rate. *Geophysical Research Letters*, *48*, e2021GL093047. Accessed at: https://doi.org/10.1029/2021GL093047

123) Since the 1980s, each successive decade has been warmer than any preceding decade since 1850.[77] Since 1978, no year has had a global mean temperature below the 1961–1990 average;[78] thus, **no one under the age of 44 has ever experienced a year in which global temperatures were 'below normal' by last century's standards.**

124) At the time of writing, the hottest year on record is 2020, at nearly the same temperature as 2016. Despite 2021 being slightly cooler to previous years due to the cooling effect of La Niña, it is still one of the hottest seven years on record.[79] **In fact, the past seven years have been the hottest seven years on record**.[80]

125) Global surface temperature was 1.09°C higher averaged over the period 2011–2020 than in the period 1850–1900, with larger increases over land (1.59°C) than over the ocean (0.88°C).[81] Given that the rate of global warming averages about 0.2°C per decade,[82] **underlying trends in global warming place the world at about 1.2°C above pre-industrial periods in 2022**, with year-to-year fluctuations.

126) **Current effects of climate change worldwide include**:[83] **increased severity of storms and heat waves, species extinction, wildfires, coastal inundation from rising sea levels and increased storm surge, and an increasing risk of crossing so-called 'tipping points'**

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[77] 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, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

[78] BOM (2020), Annual Climate Statement 2019, accessed at: http://www.bom.gov.au/climate/current/annual/aus/2019/

[79] WMO (2022) Press Release. https://public.wmo.int/en/media/press-release/2021-one-of-seven-warmest-years-record-wmo-consolidated-data-shows

[80] WMO (2021) State of Global Climate 2021, WMO Provisional Report, accessed at: https://library.wmo.int/index.php?lvl=notice_display&id=21982

[81] 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, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

[82] IPCC SR1.5 (2018) Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C. Accessed at: http://ipcc.ch/report/sr15/

[83] IPCC (2014): Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Field et al. (eds.) Cambridge University Press, pp. 1-32.

that would accelerate climate change and greatly intensify its impacts[84], **perhaps irreversibly.**

127) Global effects of climate change are already substantial and costly: [85,86]

a) **Accelerating sea-level rise**, with the observed global rate increasing 25% over the last decade, from 3.04 millimetres per year (mm/yr) during the period 1997–2006 to approximately 4 mm/yr in 2007–2016, driven in part by accelerating land ice melt from Greenland and West Antarctica.

b) **Heat waves,** which were **the deadliest meteorological hazard in the last five years**, affect all continents. Between 2000 and 2016, the number of people exposed to heat waves is estimated to have increased by 125 million.

c) **More extreme wildfires,** including the unprecedented wildfires in 2019 in the Arctic and in the Amazon rainforest, in 2020 and 2021 in California, in 2021 in Canada, and in 2019/20 in Australia.

d) **Hotter days and warmer nights** over most land areas. Globally, July 2019 had been listed as the hottest month on record, with July 2020 taking second place.[87] That first-place record has now been eclipsed by July 2021.[88]

e) **Intensification of the hydrological cycle**: that is, increases in the frequency, intensity and amount of heavy precipitation in many areas, and increases in the intensity and duration of drought in other regions.

f) **Ocean acidification**, threatening sea life and destroying entire ecosystems.

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[84] Schellnhuber HJ, Rahmstorf S, Winkelmann R (2016) Why the right climate target was agreed in Paris. *Nature Climate Change*, 6:649-653

[85] WMO (2019) United in Science, Report prepared for the UN Climate Action Summit 2019, https://wedocs.unep.org/bitstream/handle/20.500.11822/30023/climsci.pdf

[86] IPCC, SPM (2013) Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by Stocker TF, et al. Cambridge and New York, Cambridge University Press, pp 3-29. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_SPM_FINAL.pdf

[87] NOAA (2020), July 2020 was record hot for N. Hemisphere, 2nd hottest for planet**,** https://www.noaa.gov/news/july-2020-was-record-hot-for-n-hemisphere-2nd-hottest-for-planet

[88] NOAA (2021) https://www.noaa.gov/news/its-official-july-2021-was-earths-hottest-month-on-record

g) **Increases in coastal flooding**, caused by more, and more extreme, high sea level events.

128) AR6 WGII describes the current consequences of anthropogenic climate change in clear and stark terms, stating: "**The rise in weather and climate extremes has led to some irreversible impacts as natural and human systems are pushed beyond their ability to adapt**." Specifically, according AR6 WGII[89], climate change has:

a) "caused substantial damages, and increasingly irreversible losses, in terrestrial, freshwater and coastal and open ocean marine ecosystems,"

b) "reduced food and water security,"

c) "adversely affected physical health of people globally," and

d) contributed to "humanitarian crises where climate hazards interact with high vulnerability."

129) **In 2020 and 2021 alone** the following extraordinary climate events were recorded,[90,91,92,93] among many others:

a) In both 2020 and 2021, Death Valley in the United States of America (US) reported a temperature of 54.4°C, possibly the **highest temperature ever reliably recorded on Earth**.

b) In South America, **record fires burnt over a quarter of the Pantanal, the world's largest tropical wetlands**, in 2020.

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[89] IPCC (2022) Summary for Policy Makers, in Climate Change 2022: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg2/

[90] Steffen, W. and Bradshaw, S. (2021) Hitting Home: The Compounding Costs of Climate Inaction, and references cited therein. Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/hitting-home-compounding-costs-climate-inaction

[91] Blunden, J. and T. Boyer, eds. (2020) State of the Climate in 2020 in *Bull. Amer. Meteor. Soc.*, 102 (8), Si–S475, https://doi.org/10.1175/2021BAMSStateoftheClimate.1

[92] WMO (2021) State of the Global Climate 2020, Accessed at: https://library.wmo.int/index.php?lvl=notice_display&id=21880#.YOwDJOgzbIV

[93] WMO (2021) State of the Global Climate 2021, WMO Provisional report. Accessed at: https://reliefweb.int/report/world/wmo-provisional-report-state-global-climate-2021

c) **Europe had its warmest year on record**, with 17 countries reporting record average temperatures for 2020.

d) The **highest temperature**, 18.3°C, was **recorded in Antarctica in 2020**.

e) In 2021, it rained – rather than snowed – for the first time on record at the peak of the Greenland ice sheet.

f) **A heatwave in Canada** and adjacent parts of the US **pushed temperatures to 49.6°C in 2021 in a village in British Columbia, breaking the previous Canadian national record by 4.6°C**; the town was devastated by fire the next day.

g) In 2020, **Cyclone Gati**, the strongest landfalling cyclone recorded in Somalia, **brought over a year's worth of rain in 24 hours to its city of Bosaso**.

h) In 2020, **wildfires in California displaced 100,000 people from their homes**. The area burnt in California in 2021 is larger than that burnt in 2020,[94] which itself set records for the state.

i) **Super Typhoon Goni was the strongest tropical cyclone to make landfall in the historical record and led to the evacuation of almost 1 million people in the Philippines.**

j) In Siberia, an intense, persistent and widespread heat wave broke temperature records, fuelled large fires, and thawed permafrost. The Russian town of Verkhoyansk recorded **a temperature of 38°C in June 2020, likely the highest temperature ever recorded in the Arctic**.

k) Extreme rainfall hit Henan Province of China in 2021. On 20 July, **the city of Zhengzhou received 201.9mm of rainfall in one hour (a Chinese national record)**, 382mm in 6 hours, and 720 mm for the event as a whole, more than its annual average.

l) The on-going megadrought in southwestern North America has been shown to be the driest 22-year period in that area in more than 1200 years.[95]

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[94] https://www.fire.ca.gov/stats-events/

[95] Park Williams, A., Cook, B. I., and Smerdon, J. E. (2022) Rapid Intensification of the emerging southwestern North American megadrought in 2000-2021, in Nature Climate Change, Accessed at: https://www.nature.com/articles/s41558-022-01290-z

130) **The most dramatic – and previously unthinkable – heatwave ever recorded occurred in March 2022 at both of Earth's poles simultaneously. In the East Antarctic, temperatures were about 40°C warmer than average, whilst parts of the Arctic were nearly 30°C warmer than average**.[96]

6.1.2 Australia

131) Australia is witnessing serious climate-related impacts now. According to the recently released AR6 WGI, all areas of Australia have been assessed at high confidence to already be experiencing an increase in heat extremes due to human-caused climate change.[97]

132) Specifically, the Australian Bureau of Meteorology (BOM) and the CSIRO[98,99,100] report that recent climate trends include:

a) Australia has warmed by 1.44 ± 0.24°C since national recording keeping began in 1910. The seven years 2013 – 2019 all rank in the top nine warmest years on record. **Most years in Australia are now warmer than almost any year in the 20th century (2021 was an exception). Australia's hottest year and driest year on record was 2019**.

b) Increased warming, both daytime and night-time, is observed across Australia in all months, sharply increasing the number of extremely warm days. **There were 43 extremely warm days in 2019, more than triple than in any year prior to 2000**.

c) National daily average maximum temperatures have increased dramatically: **33 days exceeded 39°C in 2019, more than the number observed from 1960 to 2018 combined**, which totalled 24 days.

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[96] https://www.yahoo.com/news/eastern-antarctica-registers-temperatures-70-173500030.html and sources therein.

[97] 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, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

[98] BOM (2020), Annual Climate Statement 2020, accessed at: http://www.bom.gov.au/climate/current/annual/aus/

[99] CSIRO/BOM (2020), State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate

[100] CSIRO/BOM (2021), State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate

d) **Very warm day- and night-time temperatures** that occurred only 2% of the time in the past (1960-1989) **now occur five to six times more frequently** (2005-2019). As a result, the frequency of extreme heat events is increasing. (See Fig. 11 below.)[101]

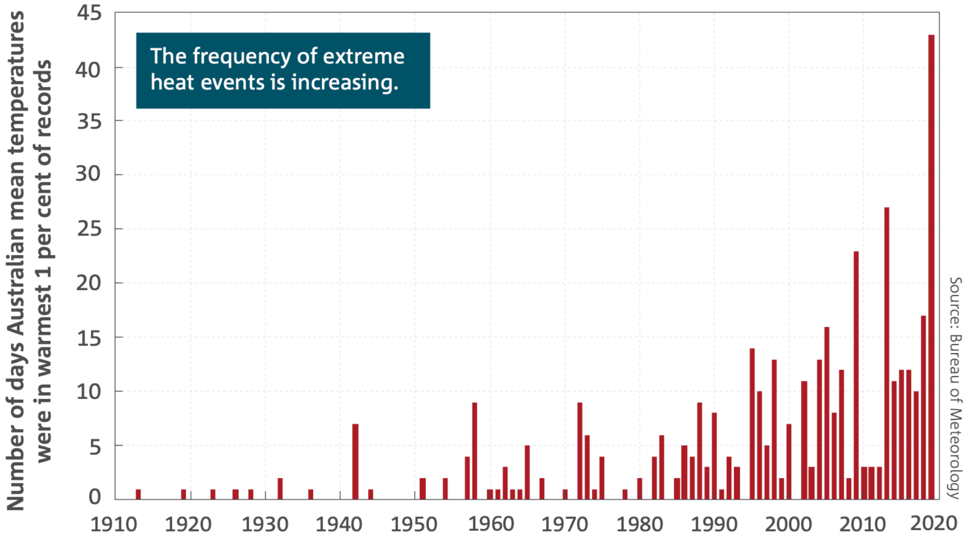

Fig. 11: Number of extreme (top 1%) heat days from 1910 to 2019. Figure from BOM.

e) In December 2019, there were 11 days for which the *national area-averaged* maximum temperature was 40 °C or above[102] (see Fig. 12 below). Only 11 other such days have been recorded since 1910, seven of which occurred in the summer of 2018–19.

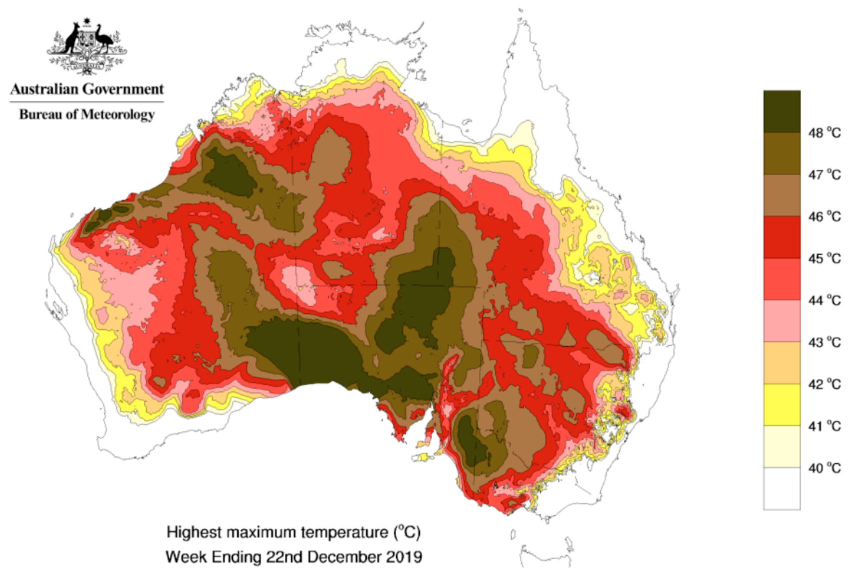

Fig. 12: Highest daily maximum temperature from 16-22 Dec 2019. Figure from BOM.

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[101] CSIRO/BOM (2020), State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate

[102] BOM (2019) Special Climate Statement 70b update. Accessed at: http://www.bom.gov.au/climate/current/statements/

f) A long-term increase in extreme fire weather, and fire-season length, has occurred across large parts of Australia, with devastating consequences. **Much of Australia now witnesses up to 25 more days with weather conditions conducive to extreme bushfires compared to 1950-1985**.[103] (See Fig. 13.)

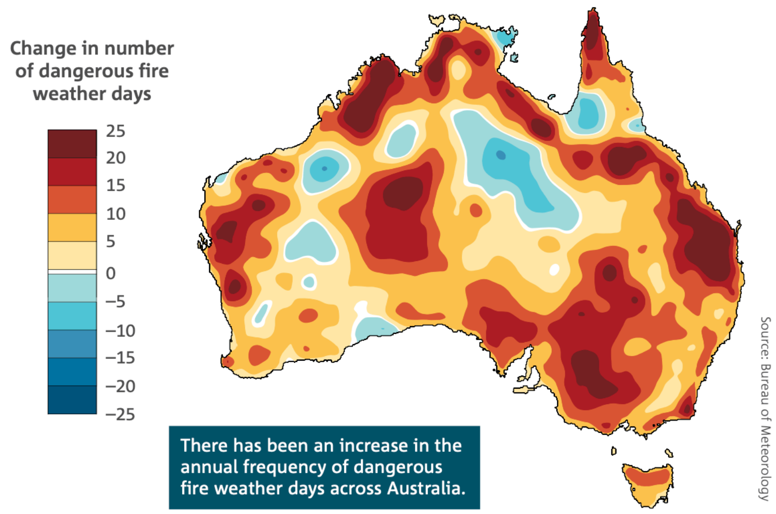

Fig. 13: Change in number of days of dangerous fire weather in 1985-2020 compared to 35 years earlier, 1950-1985.

These are days recording a Forest Fire Danger Index (FFDI) that exceeds its 90th percentile.

g) **Cool-season rainfall has declined in southeast and southwest Australia** over the past 20 years, while rainfall has increased in northern Australia. (See Fig. 14 below.)[104]

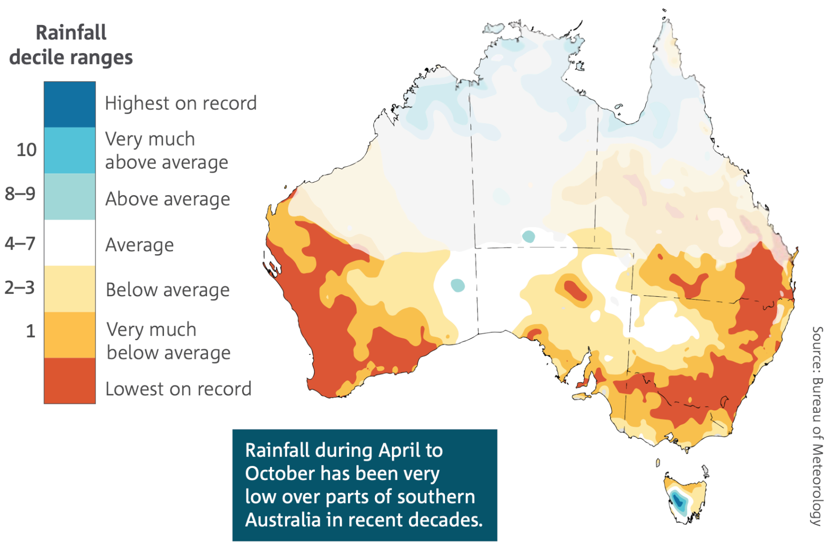

Fig. 14: April to October rainfall deciles for the last 20 years (2000 – 2019) compared to the total entire rainfall record since 1900. Figure from BOM.

h) More of the total annual rainfall in recent decades has come from heavy rain days. **Heavy rainfall events are becoming more intense**.

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[103] CSIRO/BOM (2020) State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate/

[104] CSIRO/BOM (2020), State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate

i) In part due to La Niña effects, rainfall has been above average in 2021. Major flooding occurred in multiple West Gippsland catchments after more than 200 mm of rain fell during the 24 hours in June 2021. **Daily rainfall records were set across a number of stations in Victoria and major flooding occurred in multiple catchments in 2021. It was the wettest November on record for Australia as a whole**, with flooding occurring across large areas of inland NSW and large areas of Queensland**. Now much of this has been dwarfed by the unprecedented floods in the early part of 2022** (see Sections 6.1.3 and 6.1.4)**.**

j) Ocean warming, particularly around southeast Australia and in the Tasman Sea, has contributed to **longer and more frequent marine heatwaves**, depleting kelp forests and sea grasses, increasing disease and bleaching coral reefs.

k) **Increasing acidity of oceans has accelerated, to more than five times faster than that from 1900 to 1960, and 10 times faster than at any time in the past 300 million years**. The entire marine ecosystem is affected, with a **significant reduction in coral calcification and growth rates on coral reefs such as the Great Barrier Reef**. The **widespread coral bleaching of the Great Barrier Reef during 2016 was made 175 times more likely due to climate change caused by humans**.[105]

133) A new trend, called '**flash drought' is emerging in Australia**. Flash droughts occur from a very fast reduction in soil moisture, typically caused by a lack of rainfall combined with high temperatures, low humidity, and strong winds. **Flash droughts occur so quickly that adaptation by farmers is difficult**.[106]

134) The cost of extreme weather disasters in Australia has more than doubled since the 1970s, reaching $35 billion for the decade 2010-2019. **Australians are five times more likely to be displaced by a climate-fuelled disaster than someone living in Europe**.[107]

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[105] King A, Karoly D, Black M, Hoegh-Guldberg O, and Perkins-Kirkpatrick S (2016) Great Barrier Reef bleaching would be almost impossible without climate change. The Conversation, April 29, 2016.
[106] Steffen, W. and Bradshaw, S. (2021) Hitting Home: The Compounding Costs of Climate Inaction, and references cited therein. Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/hitting-home-compounding-costs-climate-inaction
[107] Steffen, W. and Bradshaw, S. (2021) Hitting Home: The Compounding Costs of Climate Inaction, and references cited therein. Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/hitting-home-compounding-costs-climate-inaction

135) **Australia has been rated fourth highest in the G20 for economic losses per unit of GDP incurred from extreme weather events over the last 20 years** (1999-2018).[108]

136) Changes to physical systems caused by human-induced climate change have already had detrimental effects in effects on the natural environment of Australia. AR6 WGII states: **"Climate trends and extreme events have combined with exposure and vulnerabilities to cause major impacts for many natural systems, with some experiencing or at risk of irreversible change in Australia."** [109]

137) AR6 WII continues: "The region faces an extremely challenging future. **Reducing the risks would require significant and rapid emission reductions to keep global warming to 1.5–2.0°C, as well as robust and timely adaptation. The projected warming under current global emissions reduction policies would leave many of the region's human and natural systems at very high risk and beyond adaptation limits."**

6.1.3 The 2019/2020 Black Summer Fires and the 2022 Floods

138) In three years, eastern Australia has gone from unprecedented extremes in drought, heat and bushfire, to unprecedented extremes in rainfall and flooding, sometimes in the same geographical areas. This has placed enormous strain on communities, the environment, and emergency and medical response. In some areas, recovery from one catastrophe has hardly begun before another takes place.

139) **Australia is the most fire-prone continent on Earth**.[110,111] The accumulation of charcoal (fire residue) in Australia is now higher than at any other time in the last 70,000 years.[112]

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[108] Climate Transparency Report (2020) International Climate Transparency Partnership, accessed at: https://www.climate-transparency.org/g20-climate-performance/the-climate-transparency-report-2020

[109] IPCC (2022) Chapter 11, Australasia, in Climate Change 2022: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg2/

[110] Sharples, J. J. et al. (2016) Natural hazards in Australia: extreme bushfire. Clim. Chang. 139, 85–99

[111] Bradstock, R. A. (2010) A biogeographic model of fire regimes in Australia: current and future implications. Glob. Ecol. Biogeogr. 19, 145–158.

[112] Mooney, S. D. et al. (2011) Late Quaternary fire regimes of Australasia. Quat. Sci. Rev. 30, 28–46.

140) **The Forest Fire Danger Index (FFDI) indicates the fire danger on a given day** based on daily values for temperature, humidity and wind speed, and a drought factor that represents the influence of recent temperatures and rainfall events on fuel moisture. Extremely dangerous fire weather results in high FFDI values. **An FFDI larger than 50 represents 'severe' fire risk that results in a total fire ban. Fire weather drives the chances of a fire starting, its subsequent behaviour, and the difficulty of suppressing it.**

141) **In 2019, the national annual accumulated FFDI was its highest since 1950, when national records began.**[113] Accumulated FFDI reached record high values in areas of all States and Territories in Spring 2019,[114] including essentially all of NSW.

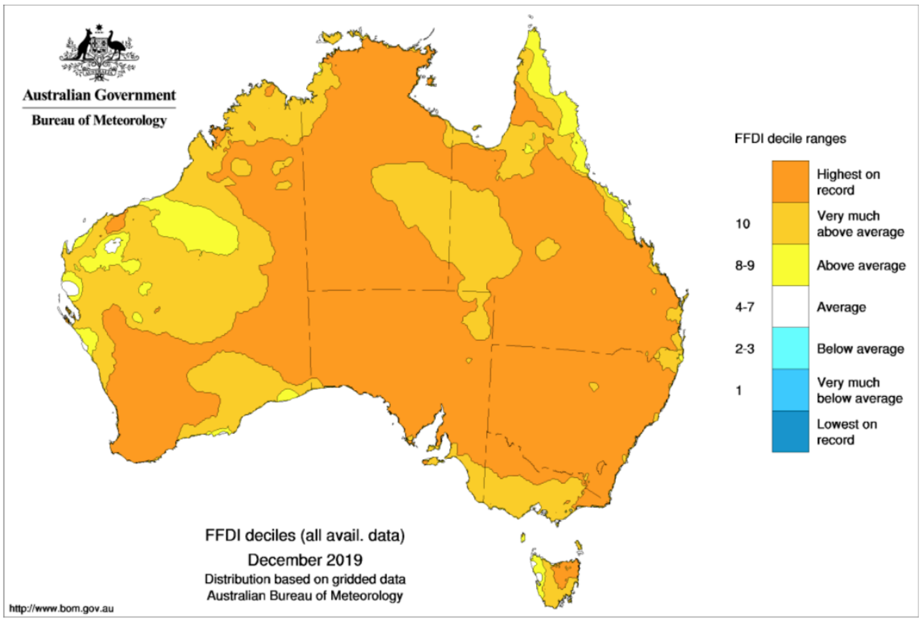

Fig. 15: FFDI deciles for December 2019, showing large areas of Australia had highest values on record for that month (dark orange colour). Figure from BOM Climate Statement 73.

142) Those dangerous fire weather conditions continued **into summer of 2019/2020, with December accumulated FFDI values the highest on record across large areas of Australia, and essentially all of NSW** (see Fig. 15 above).[115]

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[113] BOM (2020) Special Climate Statement 73 update, Accessed at: http://www.bom.gov.au/climate/current/statements/

[114] BOM (2020) Special Climate Statement 73 update, Accessed at: http://www.bom.gov.au/climate/current/statements/

[115] BOM (2020) Special Climate Statement 73 update, Accessed at: http://www.bom.gov.au/climate/current/statements/

143) It is not surprising, therefore, that **the Australian 2019/20 bushfires were the worst on record on many measures**.[116,117]

144) **Nearly 80% of all Australians were affected directly or indirectly by the 2019/20 bushfires,**[118] **which have now come to be known as the 'Black Summer' fires.**

145) The Black Summer fires resulted in extensive social, environmental and economic impacts. The direct social impacts included the loss of 33 lives[119] and the destruction of over 3,000 houses.[120]

146) The economic costs of Black Summer go beyond the direct impact on gross domestic product (GDP). Nationally, the fire season is expected to break new records for economic costs from bushfires,[121] and **was judged to be Australia's costliest natural disaster up to 2020**.[122] It remains to be seen whether those costs will be surpassed by the 2022 floods.

147) The tourism sector alone is likely to have lost at least $4.5 billion due to effects of the fires.[123] The Australian food system is estimated to have suffered at least $4–5 billion in economic losses due to the Black Summer fires, with only about a third of this recovered

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[116] Hughes, L, Steffen, W, Mullins, G, Dean, A, Weisbrot, E, and Rice, M (2020) *The Summer of Crisis.* Published by the Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/summer-of-crisis/ and references cited therein.

[117] Abram, N.J., et al. (2021) Connections of climate change and variability to large and extreme forest fires in southeast Australia, Communications Earth & Environment 2:8, https://doi.org/10.1038/s43247-020-00065-8

[118] Biddle et al. (2020) Exposure and the impact on attitudes of the 2019-20 Australian Bush Fires. ANU Centre for Social Research Methods. Accessed at: https://csrm.cass.anu.edu.au/sites/default/files/docs/2020/2/Exposure_and_impact_on_attitudes_of_the_2019-20_Australian_Bushfires_publication.pdf

[119] Hughes, L, Steffen, W, Mullins, G, Dean, A, Weisbrot, E, and Rice, M (2020) *The Summer of Crisis.* Published by the Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/summer-of-crisis/ and references cited therein.

[120] Filkov, A. I., Ngo, T., Matthews, S., Telfer, S. & Penman, T. D. (2020) Impact of Australia's catastrophic 2019/20 bushfire season on communities and environment. Retrospective analysis and current trends. J. Safe. Sci. Resil. 1, 44–56

[121] ANZ Research (2020) Australian bushfires: Impacting GDP. Accessed at: https://bluenotes.anz.com/posts/2020/01/anz-research-australian-bushfires-economic-impact-gdp

[122] Read, P. & Denniss, R. (2020) With costs approaching $100 billion, the fires are Australia's costliest natural disaster. Conversation. Accessed at: https:// theconversation.com/with-costs-approaching-100-billion-the-fires-are- australias-costliest-natural-disaster-129433

[123] AFR (Australian Financial Review) (2020) Tourism loses $4.5b to bush res as overseas visitors cancel. Accessed at: https://www.afr.com/companies/tourism/tourism-loses-4-5b-to-bushfires-as-overseas-visitors-cancel-20200116-p53s0s/

through funding for bushfire recovery. In NSW, over **600,000 hectares of pasture was burnt and nearly 90,000 linear kilometres (km) of agricultural boundary fencing damaged.** [124]

148) **Indirect health impacts attributed to smoke exposure include an estimated 417 lives lost and 3,151 hospitalisations**.[125] The short-term health costs associated with this smoke exposure is estimated to be $1.95 billion Australia-wide, **with $1.07 billion attributed to NSW losses.**[126] The longer-term premature mortality and economic burden from cumulative effects of smoke exposure will be much higher, by factors estimated to be between two and five.[127]

149) Other long-term health impacts are difficult to quantify, but in the years following previous major fire events ongoing post-traumatic stress disorder and depression have been reported among fire-affected populations.[128] Furthermore, new research points to an under-recognised, potential health threat: microbes that thrive in pyrogenic carbon created by bushfires and can travel hundreds of kilometres once airborne, generating reduced airway conductance and inflammation.[129]

150) Overall, it is estimated that **three billion individual native vertebrates perished in the Black Summer fires**, comprising: 143 million mammals, 2.46 billion reptiles, 180 million birds and 51 million frogs.[130]

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[124] Bishop, J., Bell, T., Huang, C. and Ward, M. (2021) Fire on the Farm: Assessing the Impacts of the 2019-2020 Bushfires on Food and Agriculture in Australia, WWF and University of Sydney. Accessed here: https://www.wwf.org.au/ArticleDocuments/353/WWF Report-Fire on the Farm_converted.pdf.aspx

[125] Borchers Arriagada, N. et al. (2020) Unprecedented smoke-related health burden associated with the 2019–20 bushfires in eastern Australia. Med. J. Aust. 213, 282–283.

[126] Johnston, F.H. et al. (2021) Unprecedented health costs of smoke-related PM2.5 from the 2019-20 Australian megafires, Nature Sustainability, 4, 42-47.https://doi.org/10.1038/s41893-020-00610-5

[127] Johnston, F.H. et al. (2021) Unprecedented health costs of smoke-related PM2.5 from the 2019-20 Australian megafires, Nature Sustainability, 4, 42-47, and Extended Data Fig. 3. https://doi.org/10.1038/s41893-020-00610-5

[128] Bryant, R. A. et al. (2014) Psychological outcomes following the Victorian Black Saturday bushfires. Aust. N. Z. J. Psychiatry 48, 634–643.

[129] Kobziar, L. & Thompson, G.R. (2020) Wildfire smoke, a potential infectious agent: Bacteria and fungi are transported in wildland fire smoke emissions , Science, 18 December 2020, 370, 6523, p 1408-1410. Accessed at: https://science.sciencemag.org/content/370/6523/1408

[130] Van Eeden, L. et al. (2020) Australia’s 2019-2020 Bushfires: The Wildlife Toll Interim Report, WWF Australia. Accessed from: https://www.wwf.org.au/news/news/2020/3-billion-animals-impacted-by-australia-bushfire-crisis

151) **In NSW, 37% of the state's rainforests were fire-affected during Black Summer, including over half of the Gondwana Rainforests, an Australia World Heritage Area.[131] These ecosystems are not considered to be resilient to fire**.[132,133] Even in ecological communities that are resilient to fire, such as resprouting eucalypt forests, severe drought had already stressed ecosystems ahead of the Black Summer fires.[134] Recurrent fire damage in some areas may impair the ability of ecosystems to recover.[135]

152) **Temperate broadleaf and mixed (TBLM)** forests in eastern Australia cover about 27 million hectares (Mha); **about half of that forest area lies in NSW**. **In Australia, typically less than 2% of temperate broadleaf forest areas burn annually**, even in extreme fire seasons. The average annual area burnt for most continents is well below 5%, except for Africa and Asia, which have average annual areas burnt of 8-9% for some biomes.[136]

153) Research substantiates that the **Black Summer fires burned a globally unprecedented percentage of any continental forest biome: at least 21% of the TBLM forest biome was burnt in a single season**.[137]

154) Although the **forest areas lost in Black Summer could, in principle, be recovered by regrowth and replanting**, this will only **take place when the new trees reach full maturity in roughly 100 years**,[138,139] which is **longer than the time left to reach net zero emissions,**

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[131] State of NSW Department of Planning Industry and Environment (2020) NSW Fire and the Environment 2019-20 Summary: Biodiversity and landscape data and analyses to understand the effects of fire events. 20pp. (NSW Government, 2020).
[132] Bowman, D. M. J. S. (2000) Australian Rainforests: Islands of Green in a Land of Fire. (Cambridge University Press, 2000).
[133] Dr Patrick Norman (22 January 2021) as quoted in https://inqld.com.au/statewide/2021/01/22/forests-under-fire-black-summer-recovery-still-in-the-wilderness-reports-show/
[134] De Kauwe, M. G. et al. (2020) Identifying areas at risk of drought-induced tree mortality across South-Eastern Australia. Glob. Chang. Biol. 26, 5716–5733.
[135] Lindenmayer, D. B. & Taylor, C. (2020) New spatial analyses of Australian wildfires highlight the need for new fire, resource, and conservation policies. Proc. Natl Acad. Sci. USA 117, 12481.
[136] Boer MM, Resco de Dios V, & Bradstock RA (2020) Unprecedented burn area of Australian mega forest fires, Nature Climate Change.
[137] M. M. Boer, V. Resco de Dios, R. A. Bradstock, (2020) Unprecedented burn area of Australian mega forest fires. Nat. Clim. Chang. 10, 171–172. doi: 10.1038/s41558- 020-0716-1
[138] Ngugi MR, Doley D, Cant M & Botkin DB (2015) Growth rates of Eucalyptus and other Australian native tree species derived from seven decades of growth monitoring. Journal of *Forestry Research*, 26 (4) and references therein.
[139] Land for Wildlife. How to Age Trees. Accessed at: https://www.lfwseq.org.au/how-to-age-trees/

for even a 2°C global warming threshold. Moreover, it is not clear that these forests can fully recover in a climate that continues to warm and dry as a result of climate change.[140]

155) Consequently, **local tipping points in some Australian forests may have already been crossed.**[141] The future of these forests will be unlike their historical past, with a **danger that large portions may not be able to regenerate fully due to increased climate change and/or before the next catastrophic wildfire**.

156) Australia's Black Summer is consistent with previous scientific assessments dating back at least 30 years that human-caused climate warming will increase the duration, frequency and intensity of forest fires in southeast Australia.[142,143,144]

157) **Since the mid-twentieth century, the clear trend is towards more dangerous forest fire weather in Australia, and increasingly long fire seasons that start earlier.**[145,146,147]

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[140] Science News Magazine (2020) Will Australia's forests bounce back after devastating fires? Posted 11 February 2020. Accessed at: https://www.sciencenews.org/article/australia-forest-ecosystem-bounce-back-after-devastating-fires

[141] Steffen, W. and Bradshaw, S. (2021) Hitting Home: The Compounding Costs of Climate Inaction, and references cited therein. Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/hitting-home-compounding-costs-climate-inaction

[142] Beer, T., Gill, A. M. & Moore, P. H. R. (1988) in Greenhouse: Planning for Climatic Change (ed. Pearman, G. I.) 421–427 (CSIRO Publishing)

[143] Reisinger, A. et al. (2014) in Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. (eds V. R. Barros et al.) Ch. 25, 1371–1438 (Cambridge University Press, 2014).

[144] Hennessy, K. et al. (2007) Australia and New Zealand in Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (eds Parry, M. L. et al.) 507–540 (Cambridge University Press, 2007).

[145] Harris, S. & Lucas, C. (2019) Understanding the variability of Australian fire weather between 1973 and 2017. PLoS ONE 14, e0222328.

[146] Dowdy, A. J. (2018) Climatological variability of fire weather in Australia. J. Appl. Meteorol. Climatol. 57, 221–234.

[147] Abram, N.J., et al. (2021) Connections of climate change and variability to large and extreme forest fires in southeast Australia, Communications Earth & Environment 2:8, https://doi.org/10.1038/s43247-020-00065-8

These trends are strengthening. **Key climate change drivers of fire risk,** particularly in southeast Australia, **are becoming stronger**.[148,149]

158) **The 2022 Australian Floods placed an additional burden, particularly in NSW and Queensland, on communities and environments not yet fully recovered from climate extremes experienced just two to three years ago**.

159) Climate change is associated with extremes in the hydrological cycle. One fundamental reason for this is that a warmer atmosphere is capable of holding more water (before it precipitates out as rain or snow). According to AR6 WG1, on the global scale, extreme daily precipitation events are projected to intensify by about 7% for each 1°C of global warming (*high confidence*). Their frequency is also expected to increase, doubling with each degree of global temperature rise.[150] Increasingly extreme rainfall events and flooding due to global warming have been predicted for Australia and NSW, in particular. (see e.g., paragraphs 132), 197) and 211)).

160) Although not enough time has elapsed for a scientific attribution study on this particular anomaly, **the 2022 Australia floods are entirely consistent with expectations for climate change**, with the Climate Council stating that: "*Climate change is firmly embedded in the 2022 flooding emergency that swept through southeast Queensland and New South Wales with some regions experiencing rainfall that was simply off the charts*." Examples include:[151]

a) Brisbane and southeast Queensland were hit with around 60 percent of the region's annual rainfall within three days, as a `rain bomb' lingered over the region.

[148] Matthews, S., Sullivan, A. L., Watson, P., & Williams, R. J. (2012) Climate change, fuel and fire behaviour in a eucalypt forest. Global Change Biology, 18(10), 3212-3223. doi:10.1111/j.1365-2486.2012.02768.x

[149] Pitman, A. J., Narisma, G. T., & McAneney, J. (2007) The impact of climate change on the risk of forest and grassland fires in Australia. Climatic Change, 84(3), 383-401. doi:10.1007/s10584-007-9243-6

[150] Climate Council (2022) A Supercharged Climate: Rain Bombs, Flash Flooding and Destruction. Accessed at: https://www.climatecouncil.org.au/resources/supercharged-climate-rain-bombs-flash-flooding-destruction/

[151] Climate Council (2022) A Supercharged Climate: Rain Bombs, Flash Flooding and Destruction. Accessed at: https://www.climatecouncil.org.au/resources/supercharged-climate-rain-bombs-flash-flooding-destruction/

b) The Wilsons River in the Northern Rivers district of New South Wales, which peaked at 14.37 metres in Lismore, broke the previous flood level record by more than 2 metres.

c) Downstream at Woodburn, the river topped 7.18 metres, nearly 50% higher than its previous record of 4.92 metres.

161) **As of 9 March 2022, at least 22 people have been reported to have died from the 2022 Australian Floods,**[152] **but the number of people affected are in the tens of thousands**. According to the Climate Council:[153]

a) More than 20,000 homes in Brisbane were flooded in the disaster. Preliminary assessments indicate that more than 4,200 homes were destroyed, 1,778 severely damaged and 2,430 moderately damaged.

b) On 3 March in Sydney, a total of half a million people were under evacuation orders or evacuation warnings, and over 250 schools were closed.

c) In a 24-hour period (28 Feb – 1 March 2022), rising waters led to record numbers of New South Wales SES flood rescues – over 932.

162) Without adaptation, **projected increases in direct flood damage are 1.4 – 2 times higher at 2°C, and 2.5 – 3.9 times at 3°C of warming, compared to 1.5°C,** [154] **This is another example of the large negative consequences of allowing global warming to rise beyond 2°C.**

6.1.4 New South Wales and Wollongong Surrounds

163) This subsection outlines some of the current effects of human-caused climate change on New South Wales (NSW) and the Wollongong-Sydney surrounds, where the proposed Project would be located.

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[152] SkyNews (9 March 2022) Australia floods: National emergency to be declared as 'major catastrophe' claims 22 lives. Accessed at: https://news.sky.com/story/australia-floods-national-emergency-to-be-declared-as-major-catastrophe-claims-22-lives-12561501

[153] Climate Council (2022) A Supercharged Climate: Rain Bombs, Flash Flooding and Destruction, and references cited therein. Accessed at: https://www.climatecouncil.org.au/resources/supercharged-climate-rain-bombs-flash-flooding-destruction/

[154] IPCC (2022) Summary for Policymakers, in Climate Change 2022: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg2/

164) Most of the **climate change impacts experienced by Australia are being felt in NSW**.[155,156,157,158] What follows are just some of the consequences for NSW over the past three years alone, which has seen a swing from record-breaking drought to record-breaking floods, with a record-breaking fire season in between.

a) **NSW had its hottest and driest year in 2019, with a mean temperature 1.95°C above average and 0.27°C warmer than the previous warmest year, 2018**. Days were especially warm in 2019, with the NSW mean maximum temperature at a record high of 2.44°C above average.

b) **Penrith Lakes recorded 48.9°C on 4 January 2020, the highest temperature ever recorded in the Sydney basin**. Many sites in metropolitan Sydney exceeded 47°C. Such temperatures are dangerously hot, and place extreme thermal stress on humans and the environment. Fig. 16 shows how **extreme and widespread high temperatures** have been **in NSW over the past 20 years**.

c) NSW not only experienced extreme heat in December 2019 and January 2020, but also increased bushfire activity and poor air quality in Sydney. **NSW had its highest accumulated FFDI for December in 2019**. FFDI records date back to 1950. The extreme heat, drought and high FFDI conditions set the scene for the Black Summer Fires. (See subsection 6.1.3).

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155 BOM (2019), Annual Climate Statement 2019, NSW, accessed at: http://www.bom.gov.au/climate/current/annual/nsw/archive/2019.summary.shtml

156 BOM (2020), Annual Climate Statement 2020, NSW, accessed at: http://www.bom.gov.au/climate/current/annual/nsw/archive/2020.summary.shtml

157 BOM (2020) Special Climate Statement 73 update, Accessed at: http://www.bom.gov.au/climate/current/statements/

158 BOM (2021) Annual Climate Statement 2021, NSW, accessed at: http://www.bom.gov.au/climate/current/annual/nsw/archive/2021.summary.shtml

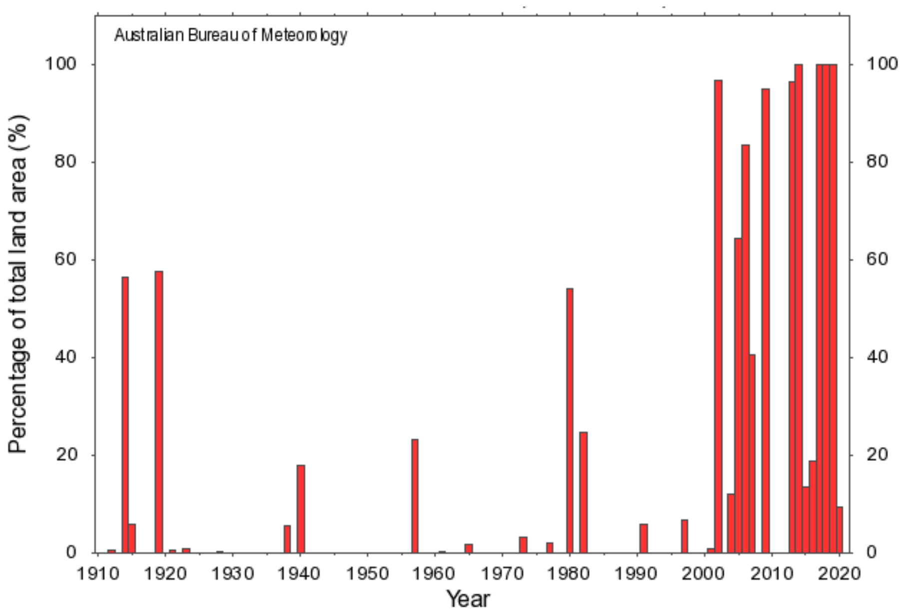

Fig. 16: The percentage of NSW area (from 0 to 100%) that experienced a maximum annual temperature in the top 10% of all records. These data from BOM cover years 1910 through 2021.

d) **Total rainfall for NSW was the lowest on record in 2019 at 55% below average; well below the previous driest year of 1944**.

e) The **unprecedented conditions of inland NSW in mid-2019 correspond to what meteorologists are now calling a 'flash drought',** conditions that were similar to those along the east coast in the months bridging 2017 and 2018.[159]

f) **Switching abruptly from record low rainfall in 2019 to heavy rain records in 2020**, many **NSW sites experienced their highest annual rainfall on record or their highest for at least 20 years**. In early 2020, coastal regions had especially heavy rain, when many sites had their highest daily rainfall on record.

g) Assisted by La Niña conditions, **heavy rainfall continued into 2021**, as coastal NSW, including Sydney, experienced multiple days of heavy rainfall. **The week ending 24 March 2021 was the wettest week for the region since national daily records began in 1900**.[160]

h) While **the March 2021 rainfall** allowed some recovery of groundwater levels in the northern Murray-Darling Basin, it **came at the expense of flooding, and was followed**

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[159] Steffen, W. and Bradshaw, S. (2021) Hitting Home: The Compounding Costs of Climate Inaction, and references cited therein. Climate Council of Australia Ltd. Accessed at: https://www.climatecouncil.org.au/resources/hitting-home-compounding-costs-climate-inaction

[160] BOM (2021) Special Climate Statement 74, Accessed at: http://www.bom.gov.au/climate/current/statements/

by more flooding in November 2021, which was NSW's wettest November on record. Some areas experienced their worst flooding in 30 years.[161]

165) **The first half of 2022 brought even more dramatic and dangerous flooding to NS**W, which was particularly bad along the coast. **Persistent intense rainfall in Sydney and along the central New South Wales coast caused widespread flash flooding and major riverine flooding, particularly in the Hawkesbury-Nepean Valley.** The widespread intense rainfall quickly overwhelmed local stormwater and drainage systems, resulting in significant flash flooding across regional and metropolitan Sydney as well as along the New South Wales coast. Severe weather and major flood warnings were issued, and thousands of people were evacuated from the affected areas.[162]

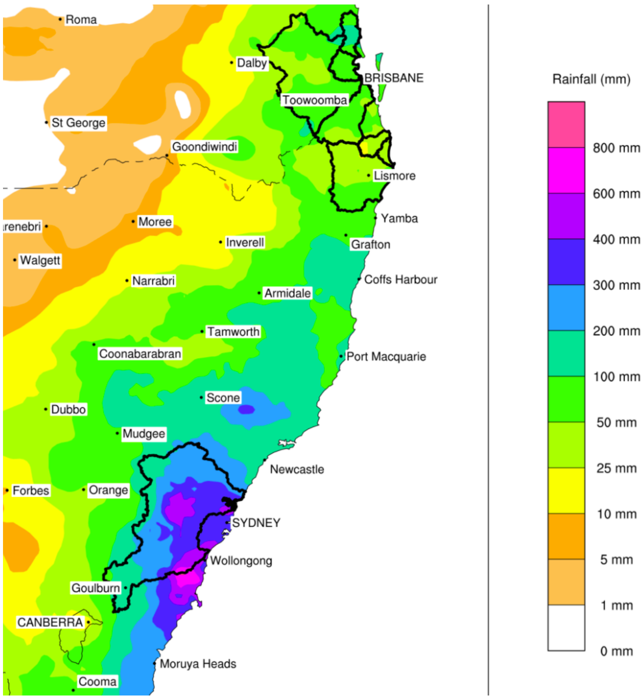

Fig. 17: Map of 7-day rainfall totals for south-eastern Queensland and eastern NSW for the week ending 9 March 2022.

Source: BOM (2022) Special Climate Statement 76.

166) Whilst **the Lismore area felt the most devastating effects overall, the Hawkesbury-Nepean catchment recorded its wettest 9- and 14-day periods on record (since 1900) to 9 March 2022**, with major flooding recorded at locations along the Nepean and Hawkesbury Rivers. Major flooding was also recorded in the New South Wales Hunter Valley (see Fig. 17 above).

[161] BOM (2021) Special Climate Statement 75, Accessed at: http://www.bom.gov.au/climate/current/statements/

[162] BOM (2022) Special Climate Statement 76, Accessed at: http://www.bom.gov.au/climate/current/statements/

167) According to BOM,[163] the 7-day period from 2–8 March, was comparable to the wettest 7-day period on record (since 1900) for the Hawkesbury-Nepean catchment average rainfall, which was set just two years earlier in February 2020. Fourteen-day totals were even more significant, with the **Hawkesbury-Nepean, Upper Nepean, Georges-Sydney Coast and Wollongong Coast catchments all setting records (since 1900) by substantial margins**.

168) There has been an increase in the intensity of heavy rainfall events in Australia. The intensity of short-duration (hourly) extreme rainfall events has increased by around 10% or more in some regions in recent decades, with larger increases typically observed in the north of the country. **As the climate warms, heavy rainfall events are expected to continue to become even more intense.** [164]

169) South-east NSW, in which the proposed Project would be sited, has experienced a noticeable rise in hot days over the past 30 years.[165]

6.2 Future Impacts of Climate Change

170) At its simplest level, **future climate change can be projected on the basis of different scenarios for future human GHG emission trajectories**.

171) Other drivers of future climate change include **the speed with which the planet responds to feedbacks in the Earth System**, and how these interact with one another, possibly cascading to create a planetary tipping point. (These are discussed in subsections 3.7, 3.8 and 3.9 of this Report.)

172) A brief overview of possible emission trajectories and their consequences for global warming levels is presented in subsection 6.2.1, making comparisons with the warming target of the UNFCCC **Paris Agreement,**[166] which **commits signatories to "holding the**

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[163] BOM (2022) Special Climate Statement 76, Accessed at: http://www.bom.gov.au/climate/current/statements/
[164] CSIRO/BOM (2020) State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate/
[165] BOM (2019) South East NSW Regional Weather and Climate Guide, Accessed at: http://www.bom.gov.au/climate/climate-guides/
[166] UN (2015), Paris Agreement, Accessed from https://unfccc.int/sites/default/files/english_paris_agreement.pdf

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." Australia is a signatory to the Paris Agreement.

173) Possible climate futures for the world, Australia and NSW are sketched below in Sections 6.2.2 , 6.2.3, and 6.2.4, respectively. Which of these futures is realised depends on the trajectory of human GHG emissions.

6.2.1 Why emissions trajectories matter

174) Projections of how the climate will evolve into the future depend on the direction and speed with which global emissions evolve. **If the trend of rising emissions is continued**, the world will be on a pathway similar to the scenarios[167] labelled RCP6.0 and RCP8.5 by the fifth Assessment Report (AR5) of the IPCC,[168] based on extrapolation of observed emissions trends,[169] and consistent with recent analyses.[170] In this case, **global warming could be 3—4°C above pre-industrial times in just 80 years**.

175) AR6 WGI,[171] expands this older work, **using improved climate modelling constrained by previous climate responses to consider five illustrative scenarios for how human emissions may proceed from now until the year 2100**. Those scenarios are labelled: SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5, in order of lowest to highest emissions.[172] They are similar, but not identical, to the RCP-labelled scenarios of the fifth IPCC assessment. The global warming consequences of each of these five emissions scenarios are shown in Fig. 18 below.

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[167] NB: "RCP" is Representative Concentration Pathway, which is a scenario for the concentration of greenhouse gases in the atmosphere. The numbers refer to the 'radiative forcing' for a scenario, in Watts per square metre.
[168] Collins, M. et al. (2013) Long-term climate change: Projections, commitments and irreversibility, in Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by Stocker et al. Cambridge University Press, pp. 1029-1136.
[169] Le Quéré, C et al. (2018) Global Carbon Budget 2018, Earth Syst. Sci. Data, 10, 2141–2194, https://doi.org/10.5194/essd-10-2141-2018
[170] Climate Action Tracker (2020) https://climateactiontracker.org/global/cat-thermometer/
[171] https://www.ipcc.ch/report/ar6/wg1/#FullReport
[172] 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, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

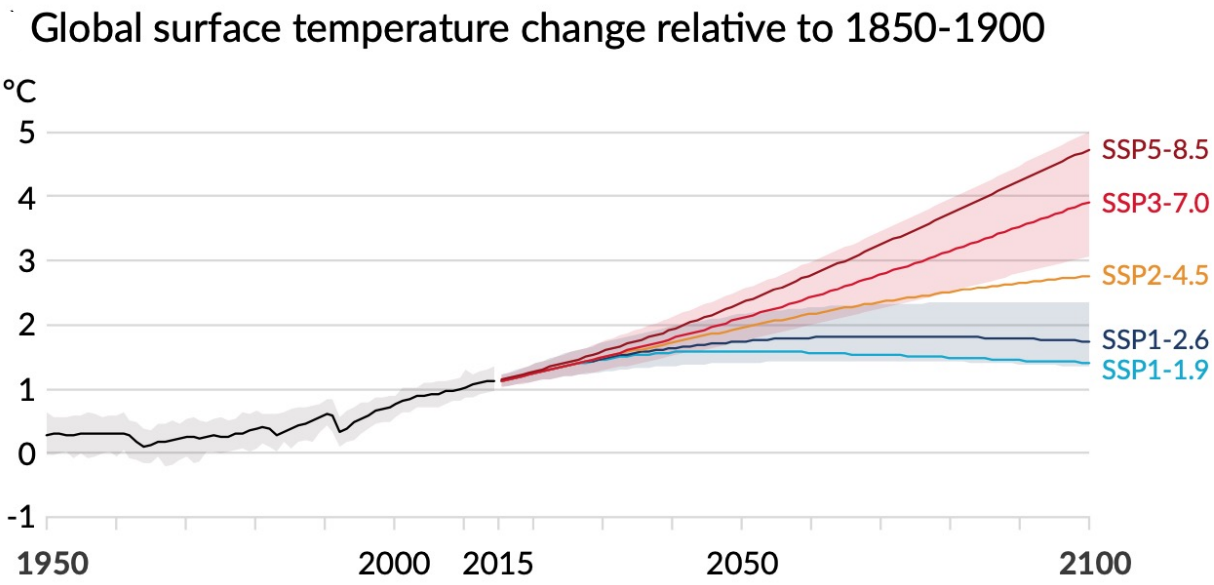

Fig 18: Projections for each of the five AR6 emission scenarios are shown in colour. The black curve indicates past warming. Shaded regions show the `very likely' ranges for the SSP1-2.6 and the SSP3-7.0 scenarios. Figure reproduced from the IPCC ARC WGI Summary for Policymakers, Fig. SPM.8.

176) ***All* scenarios considered in AR6 WGI, including the lowest emission trajectory (SSP1–1.9), are more likely than not to reach or exceed 1.5°C of warming this century.** The best estimate for the lowest emission scenario (SSP1-1.9) is that 1.5°C will be reached before 2040, likely peaking at 1.6°C around mid-century, and that warming will then drop slightly to 1.4°C at century's end.[173] **This means that humanity has likely lost the chance to hold warming strictly below 1.5C, the lowest of the Paris Agreement targets, but may still have the possibility of returning global temperatures to that value in 80 years' time.**

177) Indeed, due to natural fluctuations, the world may soon experience years in which the global average temperature exceeds 1.5°C of warming. Work led by the UK Met Office shows **there is a 40% chance that the world will see global average 1.5°C warming (at least temporarily) sometime before 2025.**[174]

178) **In order to hold global warming well-below 2°C, the upper of the Paris Agreement targets**, human emissions trajectories must be more closely aligned with the SSP1-1.9 or

[173] 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, Table SPM.1, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

[174] WMO 2020, Global Annual to Decadal Climate Update: Target years 2021, and 2021-2025. Accessed at: https://hadleyserver.metoffice.gov.uk/wmolc/ on 17 December 2021.

SSP1-2.6 scenarios than the other three scenarios, requiring "**deep reductions in CO_2 and other greenhouse gas emissions occur in the coming decades**,"[175] according to the AR6 WGI report.

179) The **higher emission scenarios SSP2-4.5, SSP3-7.0 and SSP5-8.5 all carry a significant of risk of global warming of at least 3°C by 2100, with SSP3-7.0 and SSP5-8.5 very likely to reach 3°C to 4°C by then, and continue to rise thereafter**.

180) The subsections that follow describe possible climate futures in a world experiencing different levels of global warming, including 1.5°C (which is now essentially inevitable), 2°C, 3°C and higher above pre-industrial times. **What separates these possible futures is the trajectory of human GHG emissions, particularly in the next decade**.

6.2.2 Possible Global Futures

181) **Climate impacts are hitting harder and sooner than previous scientific assessments have expected.** Over two decades, the IPCC has published a series of science-based risk assessments for people, ecosystems and economies worldwide. **A comparison of these "Reasons for Concern"** (see Fig. 19 below based on the WMO 2019 report and AR6 WII)[176] **shows that the level of risk has increased with each subsequent analysis from 2001 to 2022**. More recent IPCC reports indicate higher risks (redder colours) than did previous reports for the same average global warming.

[175] 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, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

[176] WMO 2019, United in Science, Report prepared for the UN Climate Action Summit 2019, https://wedocs.unep.org/bitstream/handle/20.500.11822/30023/climsci.pdf

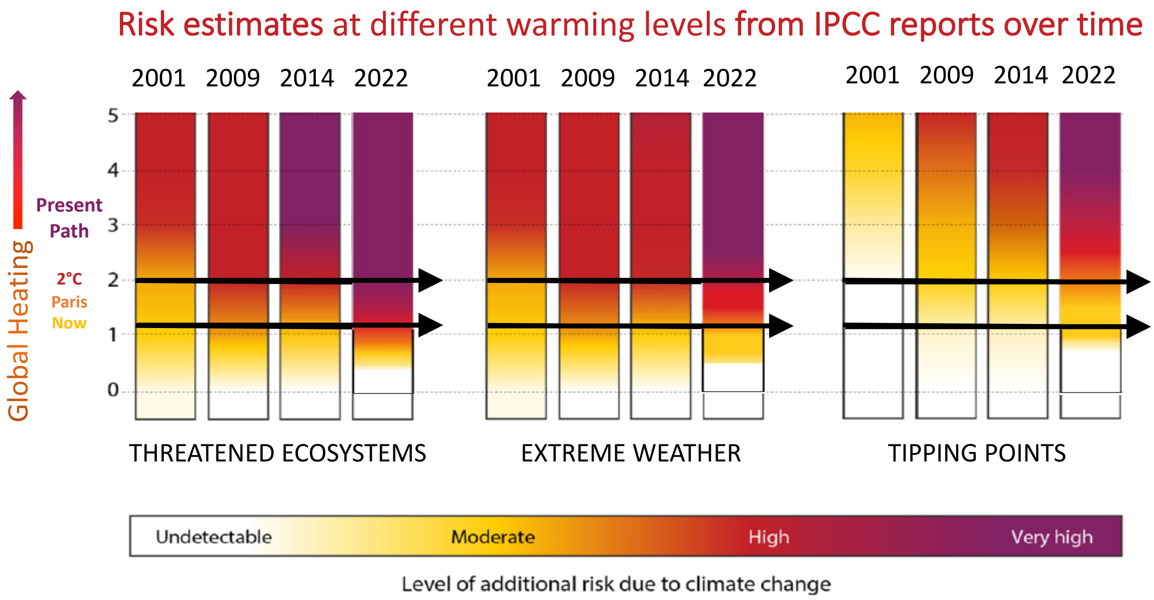

Fig. 19: As temperature (above pre-industrial time) climbs upward, climate risks increase (shown by deeper, dark colours). Indicated are the present (marked as "now"), the Paris Agreement Range, a 2°C scenario, and the present path trajectory leading to 3°C to 4°C of global heating. Results from more recent IPCC reports (arrows moving left to right) indicate higher risks than did earlier reports at the same temperature.

182) The conclusion is clear**: the more we know, the more we realise how dangerous even a small amount of warming can be**.

183) We now know that the Earth will experience 1.5°C of warming (see paragraph 176), and so it is clear that the world faces still greater risks from climate change.

184) **The Paris Agreement range of 1.5°C to well below 2.0°C is not 'safe' (though it is much safer than higher temperatures).** Within this range of warming, ecosystems are at high to very high risk, there is a high risk of extreme global weather events, and a moderate risk of large-scale singular events that could lead to climatic tipping points, as Fig. 19 shows.

185) According to AR6 WGI: "**With every additional increment of global warming, changes in extremes continue to become larger**. For example, every additional 0.5°C of global warming causes clearly discernible increases in the intensity and frequency of hot

extremes, including heatwaves (*very likely*), and heavy precipitation (*high confidence*), as well as agricultural and ecological droughts in some regions (*high confidence*)."[177]

186) Recent research indicates that **even under 1.5°C of warming, thousands of global locations will experience what are now considered 'once-in-100-years extreme-sea-level events' *at least once a year* by 2100**.[178]

187) **Very high extinction risk for endemic species in biodiversity hotspots is projected to at least double from 2% between 1.5°C and 2°C global warming levels and to increase at least tenfold if warming rises from 1.5°C to 3°C**.[179]

188) **At 2°C warming, 99% of the world's coral reefs, including the Great Barrier Reef, are very likely to be eliminated**, and **crisis upon crisis will compound for the world's most vulnerable people.**[180]

189) Specifically, **if emissions do not come down drastically before 2030, the world will be on a path to 2°C of warming or more**, and **by 2040 some 3.9 billion people are likely to experience major heatwaves, 12 times more than the historic average.** By the 2030s, 400 million people globally each year are likely to be exposed to temperatures exceeding the workability threshold. Also, **by the 2030s, the number of people on the planet exposed to heat stress exceeding the survivability threshold is likely to surpass 10 million a year.**[181]

190) Although agriculture will need to produce almost 50% more food by 2050, yields could decline by 30% and **by 2040, the average proportion of global cropland affected by**

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[177] 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, Table SPM.1, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

[178] Tebaldi, C. et al. (2021) Extreme sea levels at different global warming levels. In Nature Climate Change, 11, 746-751, https://doi.org/10.1038/s41558-021-01127-1

[179] IPCC (2022) Summary for Policy Makers, in Climate Change 2022: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg2/

[180] IPCC SR1.5 (2018) Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C. Accessed at: http://ipcc.ch/report/sr15/

[181] Quiggin, D, De Meyer, K, Hubble-Rose, L, and Froggatt, A. (2021) Climate change risk assessment 2021, Royal Institute of International Affairs, Chatham House. Accessed at: https://www.chathamhouse.org/2021/09/climate-change-risk-assessment-2021

severe drought will likely rise to 32% a year, more than three times the historic average.[182]

191) In a world of **2°C of warming**, the **extraordinary heatwave in the 2021 Pacific Northwest of the US and Canada would be hotter, and occur once every 5 to 10 years.**[183]

192) **At 2°C of warming, which current policies and actions would ensure** (see subsection 7.1), **13% of the Earth's surface will undergo complete ecosystem transformations.**[184]

193) **At 3°C–4°C of warming** above pre-industrial temperatures (a possible consequence of continuing on our current path), today's world would be nearly unrecognisable, with high to very high risk that:[185]

a) **Most of the world's ecosystems are heavily damaged or destroyed**;

b) **Extreme weather events are far more severe and frequent** than today;

c) **Large areas of the world become uninhabitable. Migration and conflict escalate**;

d) **Aggregated global impacts significantly damage the entire global economy**; and

e) A **high risk** that a cascade of tipping points in the climate system drives the **Earth system into a state not seen for millions of years**, irrespective of humanity's late attempts to reduce emissions.[186]

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[182] Quiggin, D, De Meyer, K, Hubble-Rose, L, and Froggatt, A. (2021) Climate change risk assessment 2021, Royal Institute of International Affairs, Chatham House. Accessed at: https://www.chathamhouse.org/2021/09/climate-change-risk-assessment-2021

[183] Phillip, S.Y. et al. (2021) Rapid attribution analysis of the extraordinary heatwave on the Pacific Coast of the US and Canada June 2021, Earth System Dynamics, Accessed at: https://esd.copernicus.org/preprints/esd-2021-90/

[184] IPCC SR1.5 (2018) Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C. Accessed at: http://ipcc.ch/report/sr15/

[185] IPCC (2014): Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Field et al. (eds.) Cambridge University Press, pp. 1-32.

[186] Steffen W et al. (2018) Trajectories of the Earth System in the Anthropocene. *Proc. Natl. Acad. Sci. (USA)* doi:10.1073/pnas.1810141115 and associated Appendix https://www.pnas.org/content/pnas/115/33/8252.full.pdf

194) **Over the next 2000 years, global mean sea level will rise by about 2 – 3m if warming is limited to 1.5°C, 2 – 6m if limited to 2°C, and 19 – 22m with 5°C of warming, and it will continue to rise over subsequent millennia** (*low confidence*).[187]

195) **At 5°C of warming or above,** which is possible in the highest emissions scenario SSP5-8.5 by the end of the century (see Fig. 18), **it has been estimated**[188] **that a mass extinction would occur comparable to the 'big five' mass extinctions over the past 450 million years that resulted in extinction of 75% of all marine species.**

6.2.3 Possible Australian Futures

196) **Key risks of increased global warming particular to Australia** that have been identified in the AR6 WII include[189]:

a) **Degradation of tropical shallow coral reefs** and associated biodiversity and ecosystem service values,

b) **Loss of human and natural systems in low-lying coastal areas** due to sea-level rise,

c) **Impact on livelihoods and incomes** due to decline in agricultural production,

d) **Increase in heat-related mortality and morbidity for people and wildlife**, and

e) **Loss of alpine biodiversity** due to less snow.

197) **Regardless of emission scenarios**, the CSIRO and BOM[190] report that **Australia will certainly experience more extreme climate effects**, including:

a) Further warming, with more extremely hot days and fewer extremely cool days.

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[187] 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, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

[188] Song, H., Kemp, D.B., Tian, L., Chu, D, Song, H., and Dai, X. (2021) Thresholds of temperature change for mass extinctions. Nature Communications 12: 4694, https://www.nature.com/articles/s41467-021-25019-2

[189] IPCC (2022) Summary for Policy Makers, in Climate Change 2022: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, accessed at: https://www.ipcc.ch/report/ar6/wg2/

[190] CSIRO/BOM (2020) State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate/

b) A **decrease in cool-season rainfall** across many regions of the south and east of Australia, with more time spent in drought.

c) A longer fire season for the south and east and an **increase in the number of dangerous fire weather days**.

d) **More intense short-duration heavy rainfall events** throughout the country.

e) Fewer tropical cyclones, a greater proportion of which will be of high intensity.

f) **More frequent, extensive, intense and longer-lasting marine heat waves**, increasing risk of frequent and severe bleaching of the Ningaloo and Great Barrier Reefs.

g) Oceans around Australia will continue to warm, rise and become more acidic.

h) **Ongoing sea level rise,** with recent research on ice sheet melting revealing that sea level rise could be higher than previously assessed.

Specifically, the CSIRO/BOM 2020 report states that:

i) **For most of the Australian coast, extreme sea levels that had a probability of occurring *once in a hundred years* are projected to become an *annual event* by the end of this century with lower emissions, and by mid-century for higher emissions**.

j) **The year 2019 was Australia's hottest year on record. That temperature is expected to be an *average* year when global mean warming reaches 1.5 °C above the pre-industrial baseline period of 1850–1900**.

k) **While the current decade is warmer than any other decade over the last century, it is also likely to be the *coolest* decade for the century ahead**.

198) Australian continental temperatures are observed to be about 1.4 times greater than global average temperatures.[191] Thus, global warming between 1.5°C and 2°C above 1850-1900 levels translates into average temperature increases of 2.1°C and 2.8°C for Australia.

[191] In general, the surface of land masses warm more quickly than the ocean due to differences in reflectivity and heat capacity. The poles or land near the poles warm more quickly due to ice loss which would otherwise have a cooling effect. Other factors are also at play. See: e.g., https://climate.mit.edu/ask-mit/which-parts-planet-are-warming-fastest-and-why

199) The **intensity, frequency and duration of heatwave extremes are projected to increase in the future due to climate change.**[192] For example, **for every degree °C of global temperature rise, Australians will see about 16 more heatwaves days**, with the longest heatwave increasing in length by about 5 days.

200) Already **peak heatwaves that occurred only once per 30 years in pre-industrial (1861-1890) times in Australia**, can now be expected every 5 years. **At a global warming of 1.5°C** (which we are likely to experience by the mid-2030s), **this frequency will nearly double to once every 2.7 years.** In a world **with 3°C of average warming**, Australians will see such peak heatwaves **nearly every year**.[193]

201) **For Australia, warming of 2.0°C would be substantively different to that of 1.5°C** above pre-industrial temperatures. Added to the increased risks faced globally, the IPCC[194] has listed **Australia as a region where the change in risk in moving from 1.5°C of global warming to 2°C is particularly high with regard to**:

a) Water stress and drought,

b) Shifts in biomes in major ecosystems, including rainforests,

c) Changes in ecosystems related to the production of food,

d) Deteriorating air quality,

e) Declines in coastal tourism,

f) Loss of coral reefs, sea grass and mangroves,

g) Disruption of marine food webs, loss of finfish, ecology of marine species,

h) Heat-related mortality and morbidity, and

i) Ozone-related mortality.

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[192] Perkins-Kirkpatrick, S. E. & Gibson, P. B. (2017) Changes in regional heatwave characteristics as a function of increasing global temperature. Sci. Rep. 7, 12256.

[193] Perkins-Kirkpatrick, S.E. and Gibson, P.B. (2017) Changes in regional heatwave characteristics as a function of increasing global temperature. Nature Scientific Reports, 7: *12256.* DOI:10.1038/s41598-017-12520-2

[194] IPCC SR1.5 (2018) Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C. Accessed at: http://ipcc.ch/report/sr15/

202) **Average global temperatures in the latter half of this century, and the heat waves they induce, depend critically on human actions over the next twenty years**. Because Australia's average warming is about 1.4 times the global mean (see footnote 191), **average warming in Australia before the end of this century may reach 2.7°C** (even for a rapid action SSP1-RCP2.6 sustainable pathway) **to as high as 7°C** (for a continued fossil fuel focused SSP5-RCP8.5 pathway) above pre-industrial levels.[195]

203) Based on the Keetch-Byram Drought Index (KBDI), an indicator of soil-moisture deficit, one study[196] finds that the climate conditions expected late this century (2070 – 2100) may result in high fire potential extending to seven months in Australia (August to February). **Extreme fire danger weather like that during the Black Summer bushfire season is projected to be four times more likely if global warming reaches 2°C, compared to conditions typical in 1900.**[197]

204) **Regional temperatures are key to fire development.** This is important because Australian temperatures are higher than global averages. Modelling indicates that *regional* warming of around 4°C or more above pre-industrial is sufficient to allow megafires to occur in southeast Australia irrespective of whether drought occurs simultaneously.[198] In other words, **if GHG emissions are not curbed sharply, Black Summer-like megafires may be a common Australia feature by late century even in years with plentiful rainfall**.

205) Specifically designed to study regions in Australia, the NSW/ACT Regional Climate Modelling (NARCliM)[199] project uses downscaled climate data over 50-km regions over all

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[195] Grose, M. R. et al. (2020) Insights from CMIP6 for Australia's Future Climate. Earth's Fut. 8, e2019EF001469.
[196] Liu, Y., J. Stanturf, and S. Goodrick (2010) Trends in global wildfire potential in a changing climate. *For. Ecol. Manage.*, **259**, 685–697, doi:10.1016/j. foreco.2009.09.002
[197] Oldenborgh, G.J. et al. (2020) Attribution of the Australian bushfire risk to anthropogenic climate change*,* Natural Hazards and Earth System Sciences Discussions, Accessed at: https://doi.org/10.5194/nhess-2020-69
[198] Sanderson, B. M. & Fisher, R. A. (2020) A fiery wake-up call for climate science. Nat. Clim. Change. 10, 175–177
[199] Herold, N. (2018) Australian climate extremes in the 21st century according to a regional climate model ensemble: Implications for health and agriculture, Weather and Climate Extremes, 20, 54–68, https://doi.org/10.1016/j.wace.2018.01.001

of Australia to measure climate changes from the ‘recent past’ (1990–2009), to what might be expected in the `near’ (2020–2039) and `far future’ (2060–2079).

206) The NARCliM 1.0 future projections **use a high-emissions scenario** (SRES A2).[200] **Current emissions are tracking along this scenario; whether they do in future will depend most critically on the extent to which fossil fuels contribute to the world’s future energy mix.** When reading these projections, it is **instructive to note that an Australian born today will spend childhood and teen years in the ‘near future’, and middle age in the ‘far future’**.

207) The NARCLiM 1.0 study[201] found the following results for Australia **under their high-emissions scenario**:

a) **Daytime temperature extremes are projected to increase by up to 3.5°C** in the far future, depending on season and location.

b) Heatwave frequency, number and duration will increase significantly in the near and far future. **All capital cities will experience, at minimum, a tripling of heatwave days each year by the far future compared to the recent past, with the effect more extreme in the north**.

c) **Implications for mortality are severe**, with projected future climates leading to increases in mortality due to high temperatures in all examined capital cities. As an example, **the number of heatwave days in Brisbane would increase from about 10 in the recent past to over 50 in the period centred on 2070, resulting in higher heat-related mortality** in the city.

d) Moderate to severe drought conditions are expected in the far future in the southwest and southeast of Australia during spring.

e) The **number of days at or above 30°C in the major Australian wheat-growing regions will increase substantially**, particularly during spring when wheat is most vulnerable

[200] According to NARCLiM, “The projected warming for SRES A2 for the 2090 to 2099 period, relative to 1980 to 1999, is given by IPCC AR4 as 2.0°C to 5.9°C, with a best estimate of 3.4°C.”

[201] Herold, N. (2018) Australian climate extremes in the 21st century according to a regional climate model ensemble: Implications for health and agriculture, Weather and Climate Extremes, 20, 54–68, https://doi.org/10.1016/j.wace.2018.01.001

to temperature. Projected decreases in precipitation would **decrease the likelihood of meeting historical production levels.**

208) **The Australian Academy of Science has released a report[202] describing the risks to Australia should global warming reach 3°C or higher, as it is likely to if humanity continues its current emissions trajectory**. Some of the identified key risks to Australia at 3°C (over and above those at 1.5°C to 2°C) of global warming include:

a) **Extreme events such as heatwaves, severe storms, major floods, bushfires and coastal inundation from sea level rise would be more intense and frequent**.

b) **Many locations in Australia would become uninhabitable** due to projected water shortages.

c) Severe impacts to both flora and fauna would cause **many of Australia's ecological systems** to **become unrecognisable**,

d) Existing tree plantations would change substantially.

e) Fisheries and aquaculture industries would experience declines in profitability, and **many aquaculture fisheries enterprises may cease to exist**.

f) **Many properties and businesses would become uninsurable**.

g) **A decline in profits and business viability would likely lead to increased unemployment and possibly higher suicide rates**.

h) **Health issues related to heat stress and acute and chronic psychological stressors would increase**.

i) **Declining river flows would reduce water availability for irrigated agriculture and increase water prices**.

j) **Crop yields would decline by 5 to 50%, depending on location**.

k) **Sea level rise would transform Australia's coastal regions, with severe impacts on natural ecosystems, urban infrastructure and rural settlements, putting the health and wellbeing of many people at increasingly severe risk.**

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[202] Australian Academy of Science (2021). *The risks to Australia of a 3°C warmer world* (and references therein.) Accessed at: https:// www.science.org.au/warmerworld

6.2.4 Possible NSW Futures

209) **Future climate change will increase many already deleterious impacts for NSW.** The severity will depend on the level of global warming (and thus, emission trajectories) before net zero emissions is reached. Some risks are described below.

210) **NSW crosses five subcluster regions** used to project more local future effects of climate change, namely **East Coast South** (incl. Wollongong), **Central Slopes** (incl. Dubbo and Narrabri), **Rangelands** (incl. Broken Hill), **Murray Basin** (incl. Wagga Wagga), and the **Southern Slopes**, (incl. Batemans Bay).[203] (See Fig. 20 below).[204]

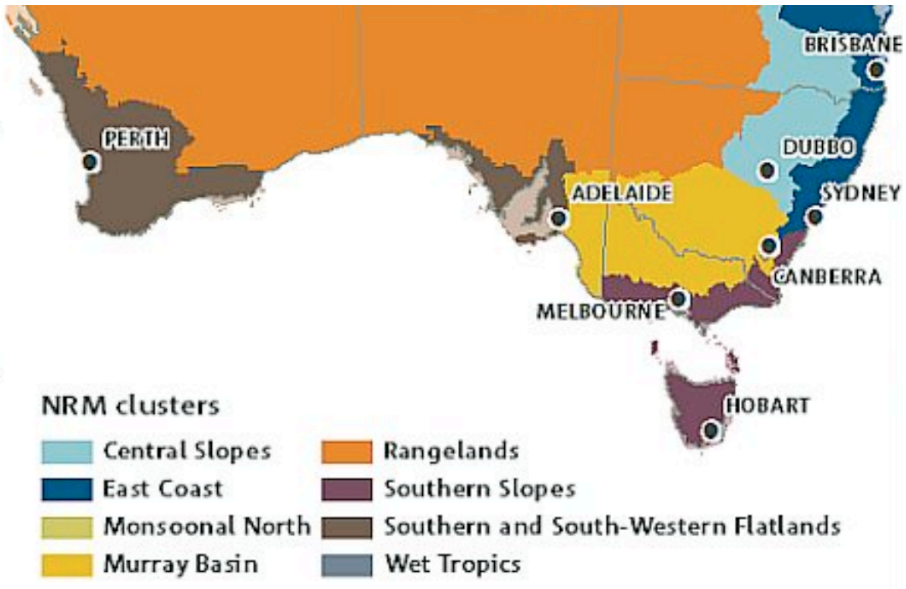

Fig. 20: Colour-coded regional clusters used to project future climate for Australia in the BOM and CSIRO `Climate Change in Australia' project.

211) Joint work[205] by the CSIRO and BoM **projects future climate conditions** by combining several global climate simulations with fine resolution "downscaled" data appropriate to local regions. **All five subclusters of NSW can expect the following in future**:

a) **Temperatures increase in all seasons, with fewer frosts in winter**.

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[203] Climate Change in Australia: NRM Regions. Accessed at: https://www.climatechangeinaustralia.gov.au/en/overview/methodology/nrm-regions/
[204] Climate Change in Australia: Projections for Australia's NRM Regions. NRM Regions. Accessed at: https://www.climatechangeinaustralia.gov.au/en/overview/methodology/nrm-regions/
[205] Climate Change in Australia (2015): Projections for Australia's NRM Regions. Accessed at: https://www.climatechangeinaustralia.gov.au/en/climate-projections/future-climate/regional-climate-change-explorer/sub-clusters/

b) **Substantial increases in the temperature on hot days, the frequency of hot days, and the duration of warm spells.**

c) **Less cool season rainfall and increased intensity of extreme rainfall events**.

212) **In addition, the East Coast South subcluster** containing the Wollongong region **in which the proposed Project would be sited, and its intended export port of Port Kembla, can expect harsher fire weather and an increasing height of extreme sea-level events.**[206]

213) A warmer atmosphere can hold more water vapour than a cooler atmosphere; this relationship alone can **increase moisture in the atmosphere by 7% for every degree Celsius of global warming, causing likelihood of heavy rainfall events**. Increased atmospheric moisture can also provide more energy for some processes that generate extreme rainfall events, which further increases the likelihood of heavy rainfall.[207] In future, **NSW can expect more frequent extreme precipitation events like those of February and March 2022**.

214) **Despite this, for many areas of NSW, runoff, that is the water available to feed dams and rivers, will decrease markedly with the multiple effects of climate change**. This is because runoff depends not only on precipitation, but also soil moisture content and soil permeability, and vegetation cover, all of which can be affected by increased surface temperature.

215) It is estimated[208] that **for every one degree of global warming, runoff will be reduced by 15%,** which matches current experience. With current global policies (see Section 7.1) leading to a possible *additional* 2°C to 3°C of temperature increase (for a total increase of 3°C to 4°C), the NSW region could be faced with water runoff reductions of 45 – 60%,

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[206] Climate Change in Australia: Regional Climate Change Explorer. https://www.climatechangeinaustralia.gov.au/en/projections-tools/regional-climate-change-explorer/sub-clusters/

[207] CSIRO/BOM (2020) State of the Climate 2020, Commonwealth of Australia. http://www.bom.gov.au/state-of-the-climate/

[208] Reisinger, A., et al. (2014) Australasia. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1371-1438.

compared to mid-last century.[209] This has **profound consequences for water availability for human and environmental use**.

216) Figure 21 shows the changes in runoff projected to affect the region surrounding the proposed Project, including **Sydney's inner drinking water catchment in 2085, if global emissions follow a trajectory similar to RCP 4.5** (see Section 6.2.1). All of the region **is expected to experience runoff reductions, with most areas experiencing at least a reduction of 10mm per year** compared to the 30-year period 1976-2005**, and the area immediately surrounding the Project experiencing more than 30mm per year reductions**.[210]

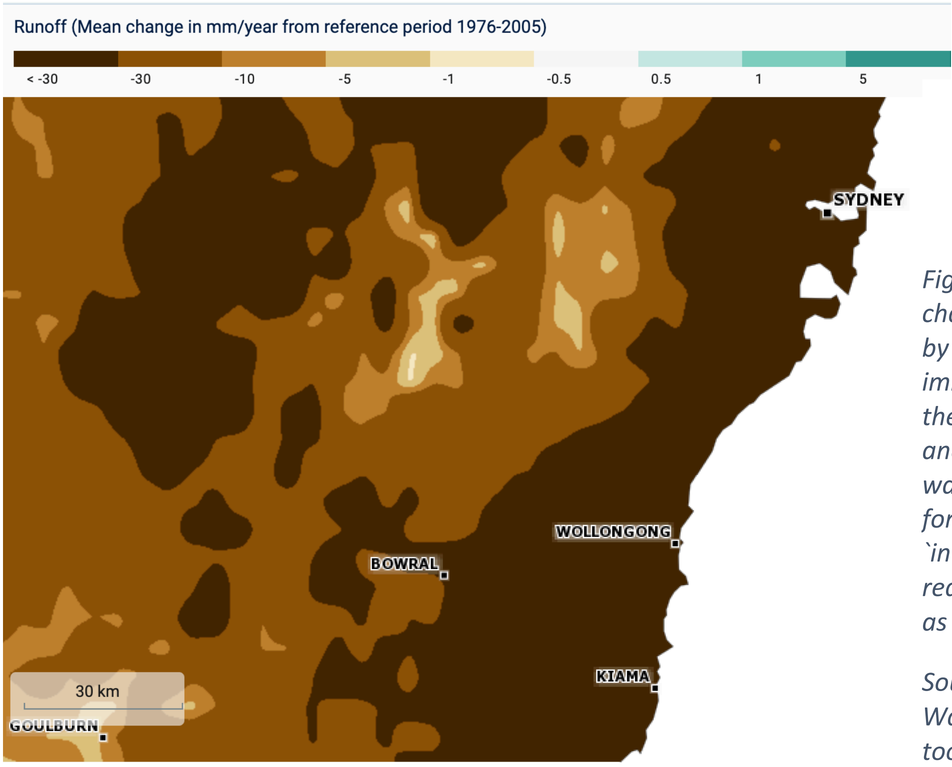

Fig. 21: Projected changes in water runoff by 2085 for the region immediately surrounding the Dendrobium Project and the inner drinking water catchment areas for Sydney, following a `intermediate' emissions reduction trajectory such as RCP 4.5.

Source: BOM Australian Water Outlook projection tool.

217) The difference in global warming between 1.5°C and 2.0°C greatly increases the frequency of extreme temperatures over many regions. For southern Australia, a median of 4–8 extra heatwave days per year is projected for every additional degree of

[209] ACT Climate Change Council (2020), Learning from Canberra's Climate-Fuelled Summer of Crisis, accessed at: https://www.environment.act.gov.au/__data/assets/pdf_file/0003/1611471/learning-from-canberras-climate-fuelled-summer-of-crisis.pdf

[210] Data and figure from BOM's Australian Water Outlook projection tool, accessed at: https://awo.bom.gov.au/products/projection/runoff/9,-34.230,150.777/nrm,-34.835,149.003/a/y/rcp45/2085

warming.[211] Consequently, **in a world with 1.5°C of warming, NSW can expect about 2–4 more heatwave days than currently, and 4–8 more with 2°C of global warming.** Should global warming reach **3°C or more**, as indicated by current policy settings in Australia and elsewhere in the world, **NSW will incur one or two more weeks in heatwave every year in addition to what it now endures.**[212]

218) The non-linear complexity of Earth's climate system is such that the most extreme of extreme temperature events do not scale simply with an additional amount of warming. One study from 2017 (before Black Summer) **concluded that major Australian cities, such Sydney or Melbourne, could therefore incur maximum summer temperatures of 50°C under 2°C of global mean warming.**[213]

219) It is important to note that **Penrith recorded 48.9°C** (whilst many other sites in metropolitan Sydney exceeded 47°C) on 4 January 2020, **at a time when global warming was about 1.1°C**. This raises the possibility that **current models may be underestimating the extreme heat that NSW will feel at 1.5°C, let alone, at 2°C of global warming.**

[211] Perkins-Kirkpatrick, S.E. and Gibson, P.B. (2017) Changes in regional heatwave characteristics as a function of increasing global temperature. Nature Scientific Reports, 7: *12256.* DOI:10.1038/s41598-017-12520-2

[212] Perkins-Kirkpatrick, S.E. and Gibson, P.B. (2017) Changes in regional heatwave characteristics as a function of increasing global temperature. Nature Scientific Reports, 7: *12256.* DOI:10.1038/s41598-017-12520-2

[213] Lewis, S. C., King, A. D., & Mitchell, D. M. (2017). Australia's unprecedented future temperature extremes under Paris limits to warming. Geophysical Research Letters, 44, 9947–9956. https://doi.org/10.1002/2017GL074612

7 Why We are Tracking Toward more Dangerous Climate Change

220) The world is emitting greenhouse gases on a trend that would lead to substantially more dangerous climate change. Indications that this is the case, and explicit requirements for reversing this trend significantly and quickly enough to minimise the damage are discussed in this section of this Report.

221) Specifically, I outline:

a) how current nationally determined contributions to the Paris Agreement are insufficient to hold warming to levels agreed by Paris Agreement signatories;

b) the shrinking remaining global 'carbon budget' to hold warming to various levels; and

c) the gap between current and planned production of fossil fuels and limiting global warming to 1.5° or even 2°C above pre-industrial temperatures.

7.1 National Contributions to the Paris Agreement

222) **The Paris Agreement**[214] **commits signatories to "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."** Signatory nations, such as Australia, have made separate, voluntary, Nationally Determined Contributions (NDCs) as a first step to meet these goals.

223) In late 2019, it was estimated that the 2019 NDCs, if achieved, would result in global warming by 2100 of 2.9°C—3.4°C relative to pre-industrial levels, increasing thereafter.[215]

224) A recent UN report[216] estimates the current 'emissions gap' between levels of warming relevant to the Paris Agreement and current NDCs. Specifically, this gap for 2030 is the difference between the estimated total global GHG emissions resulting from the full

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[214] UN (2015), Paris Agreement, Accessed from https://unfccc.int/sites/default/files/english_paris_agreement.pdf

[215] WMO 2019, United in Science, Report prepared for the UN Climate Action Summit 2019, https://wedocs.unep.org/bitstream/handle/20.500.11822/30023/climsci.pdf

[216] United Nations Environment Programme (2021) Emissions Gap Report 2021: The Heat is On – A World of Climate Promises Not Yet Delivered. Nairobi. Accessed at: https://www.unep.org/resources/emissions-gap-report-2021

implementation of the NDCs and the total global GHG emissions from least-cost scenarios that keep global warming to 2°C, 1.8°C or 1.5°C with varying levels of likelihood. Compared to previous unconditional NDCs, the **new pledges for 2030 reduce projected 2030 emissions by only 7.5%, whereas a 30% reduction (on 2010 levels) is needed for 2°C and a 55% reduction is needed for 1.5°C**. The stark difference is illustrated in Fig. 22, which visually illustrates the declines that must occur by 2030 to achieve Paris Agreement goals.

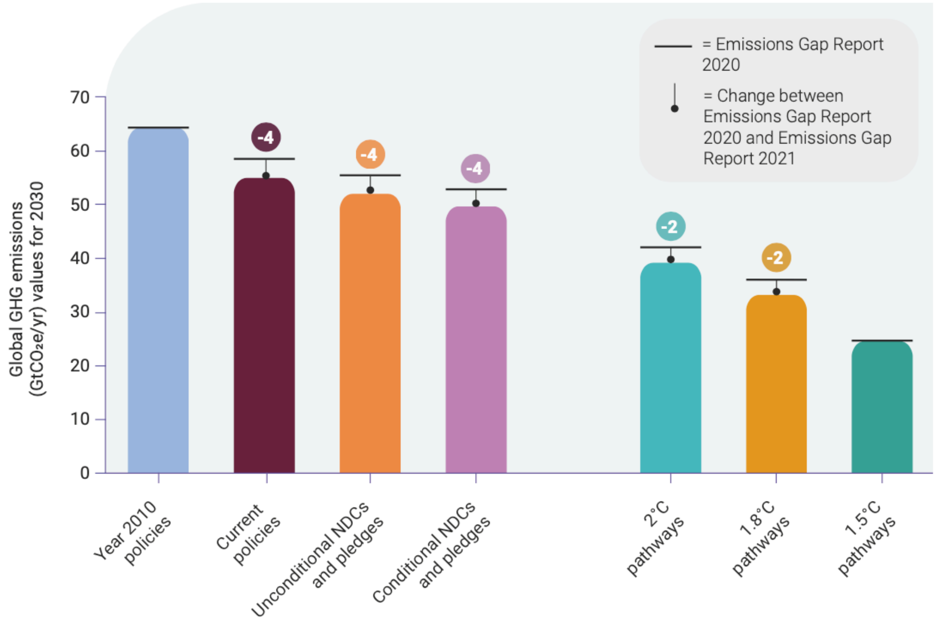

Fig. 22 (above) : Overview of changes in GHG emission projects for 2030 for different scenarios compared to global policies in 2010. Figure from the UNEP 2021 Emissions Gap Report.

225) In its most recent analysis, Climate Action Tracker[217] estimates that **global warming between 1.7°C and 2.6°C could result from current post-Glasgow pledges and targets** — **if honoured —** still falling far short of the Paris Agreement targets, but improved from expectations two years ago (see Fig. 23).

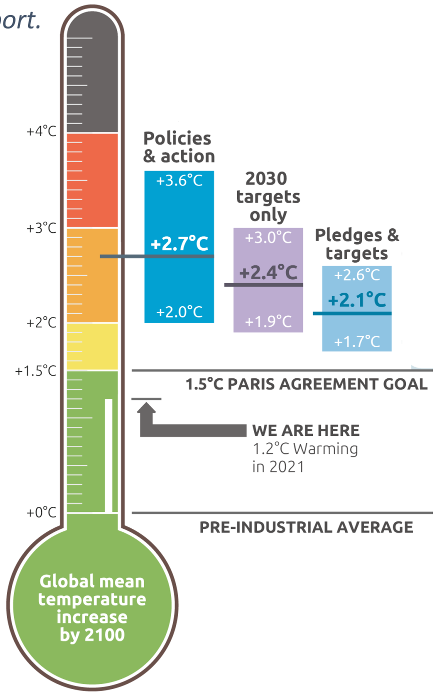

Fig. 23 (at right): Global warming projections based on pledges and policies of global nations. (Climate Action Tracker, November 2021 analysis).

[217] Climate Action Tracker (2022), https://climateactiontracker.org/ Accessed 7 June 2022.

226) Aggravating this state of affairs, **most nations are not on track to meet their current commitments**, which if not corrected immediately, would result in even more warming. In fact, **based on current *policies* as opposed to *pledges***, Climate Action Tracker estimates that **warming could go as high as 3.6°C** (see Fig. 23).[218]

227) A separate analysis indicates that **global warming might be held to `just' below 2°C if all conditional and non-conditional pledges to the Paris Agreement are implemented in full, on time, and extend indefinitely beyond the time frames for which they were promised**.[219] The analysis showed that **to improve upon this situation, 2030 targets must be strengthened, rather than 2050 targets.**

228) The devastating consequences of a world 2°C and higher are discussed in Section 6.2 of this Report.

7.1.1 Australia's Nationally Determined Contribution

229) As a nation, **Australia's Paris Agreement NDC is to reduce its emissions by 26%–28% (on 2005 levels) by 2030**.[220] It has also stated an ambition to reach net zero emissions by 2050.[221] Australia did not update its NDC targets in 2020, whereas many other nations did so. Since Australia's emissions were 624 million tonnes (Mt) CO_2-e in 2005,[222] a reduction of (at least) 26% implies emissions in 2030 of no more than 462 Mt CO_2-e.

230) As Fig. 24 below shows, there is no indication that such a decline is occurring based on the last five years of available Paris Agreement reporting data (which extends only to 2019). On current trends, then, **Australia's emission pathway is thus inconsistent with holding warming to 1.5°C**.

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[218] Climate Action Tracker (2022), https://climateactiontracker.org/ Accessed 7 June 2022.
[219] Meinshausen, M. et al. (2022) Realization of Paris Agreement pledges may limit warming just below 2°C, Nature, 604, 304.
[220] Commonwealth of Australia, Australia's 2030 Emissions Reduction Target Fact Sheet, https://pmc.gov.au/sites/default/files/publications/fact_sheet-aus_2030_climate_change_target.pdf
[221] See, e.g. https://www.pm.gov.au/media/australias-plan-reach-our-net-zero-target-2050
[222] National Greenhouse Gas Inventory, https://ageis.climatechange.gov.au

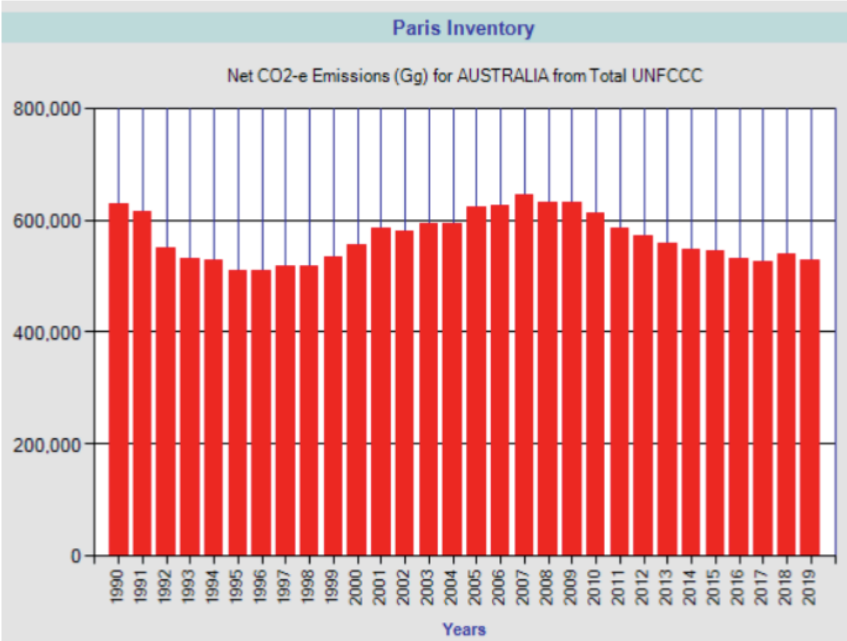

Fig 24: Australia's trend since 1990 in total emissions reported for the Paris Agreement Inventory. The plot is taken from the National Greenhouse Gas Inventory (NGGI) website. Note that the units are Gg (Giga grams) of CO_2-e, which is the same as Kt CO_2-e. (To convert to Mt CO_2-e, numbers on the vertical axis should be divided by 1000.)

231) Australia's climate targets, policies and climate finance have been rated `Highly insufficient' (by Climate Action Tracker; hereafter, CAT).[223] The `Highly insufficient' rating indicates that **Australia's climate policies and commitments are not Paris Agreement Compatible**. Specifically, according to CAT, **Australia's 2030 domestic emissions reduction target is consistent with warming of 4°C if all other countries followed a similar level of ambition**.

232) CAT notes that **the new Labor Government in Australia has committed to strengthening the country's NDC target to a 43% reduction in GHG emissions below 2005 levels by 2030** (including Land Use, Land Use Change and Forestry; hereafter LULUCF). However, they conclude that this is still far short of a reduction compatible with holding warming to 1.5°C, which would require at least a reduction of 57% in Australian domestic GHG reductions by 2030.[224]

7.2 The Global `Carbon Budget'

233) In order **to stabilise the climate at a certain average global temperature, human greenhouse gas emissions must at some point drop to net zero**. The maximum

[223] Climate Action Tracker (2022), https://climateactiontracker.org/countries/australia/, https://climateactiontracker.org/climate-target-update-tracker/australia/ Accessed on 7 June 2022.
[224] Climate Action Tracker (2022), https://climateactiontracker.org/countries/australia/, https://climateactiontracker.org/climate-target-update-tracker/australia/ Accessed on 7 June 2022.

temperature reached is determined by cumulative net global anthropogenic CO_2 emissions up until the time of net-zero CO_2, the level of non-CO_2 radiative forcing[225] in the decades just prior, and the effects of feedbacks in the Earth system (see subsection 3.7).[226]

234) **The 'carbon budget approach' is a conceptually simple and scientifically sound method to estimate the speed and magnitude by which emission reductions must occur in order to meet a desired warming target,**[227] **focussing on CO_2** as the primary greenhouse gas. This approach is used by the IPCC,[228,229] and was adopted by the Australian Climate Change Authority to form its 2014 recommendations[230] for Australia.

235) The manner in which CO_2 moves through the land, ocean and atmosphere is complex, but the full effect of these processes yields an ***approximately* linear relationship** (see Fig. 25)[231] **between**:

a) The **'carbon budget'**: that is, **the cumulative amount of carbon**[232] **emitted as carbon dioxide from human actions since the beginning of industrialisation** (often taken to be about 1870), and

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[225] Radiative forcing is the difference between how much energy from the Sun is absorbed by the Earth, and how much energy is radiated back to space. If the net forcing is zero, the Earth will remain at a stable equilibrium temperature. Positive forcing causes the temperature to rise.

[226] IPCC SR1.5 (2018) Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C. Accessed at: http://ipcc.ch/report/sr15/

[227] Collins, M. et al. (2013) Long-term climate change: Projections, commitments and irreversibility, in Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by Stocker et al. Cambridge University Press, pp. 1029-1136.

[228] IPCC SR1.5 (2018) Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C. Accessed at: http://ipcc.ch/report/sr15/

[229] 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, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

[230] CCA (Climate Change Authority) (2014) Reducing Australia's Greenhouse Gas Emissions: Targets and Progress Review—Final Report, https://www.climatechangeauthority.gov.au/reviews/targets-and-progress-review-3

[231] 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, Fig. SPM.10 accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

[232] NB: Carbon budget numbers presented here are measured in the weight of carbon emissions, not carbon dioxide. CO_2 weighs more than the carbon it contains. CO_2-e, carbon dioxide equivalent, counts greenhouse gases whose effects have already been tallied in the budget.

b) The increase in average global surface temperature since that time.

236) The **budget is not annual, but cumulative: for all time—past, present and future. Once the carbon budget has been 'spent' (emitted as GHGs), emissions must be held to net zero**[233] from that point onward to avoid exceeding the target temperature. Carbon emissions budgets are generally calculated in either billions of tonnes of carbon (Gt C) or billions of tonnes of CO_2 (Gt CO_2). 1Gt CO_2 contains 0.273 Gt C.

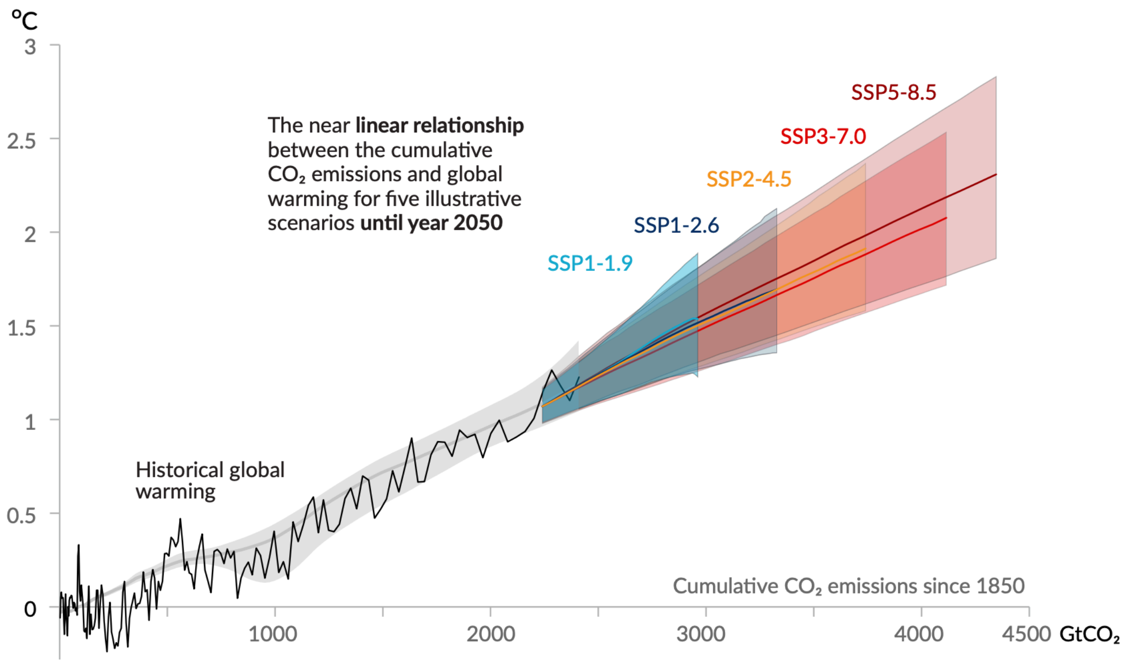

Fig. 25: Global surface temperature increase [on vertical axis in °C since the period 1850-1900] as a function of the cumulative CO_2 emissions [on horizontal axis in GtCO$_2$] projected out until the year 2050. This nearly linear (straight-line) relationship is the basis for computing a `carbon budget' for a particular amount of global warming. Figure is taken from the IPCC AR6 WGI Summary for Policymakers.

237) Several assumptions influence the size of the global carbon budget for a given warming target. Key among them are:

a) What is considered an 'acceptable' probability of meeting the target,

b) The date period used for 'pre-industrial,'

c) The accounting of other greenhouse gases (particularly CH_4 and N_2O),

d) Whether or not 'temporary overshoot' of the desired warming target is allowed, and

[233] NB: The term 'net zero' used here means that CO_2 emissions *into* the atmosphere are matched in magnitude by CO_2 removal *from* the atmosphere. Carbon capture and storage and many other `Negative Emission Technologies' are not yet viable at scale.

e) If, and how, carbon feedbacks in the climate system are accounted. Carbon feedback occurs when warming causes the Earth to release some of its own sequestered CO_2.

238) The goal is to ascertain the ***remaining* amount of carbon** (in the form of CO_2) **that humans can still release** into the atmosphere **without exceeding global warming at a prescribed level,** for example warming of 1.5°C. The *remaining* carbon budget, the amount humans have 'left to spend,' is **different from the total carbon budget, for three primary reasons**.

a) Substantial historical emissions from pre-industrial times through to the present have already been emitted, and must be subtracted from the total budget to arrive at the much smaller amount remaining.

b) Assumptions about the future emissions of *non*-CO_2 GHGs are implicit in carbon budget estimates. Should actual trajectories differ from those assumptions, the remaining carbon budget will change.

c) Some carbon cycle feedbacks, such as the abrupt shift of the Amazon rainforest to a savanna, GHG emissions from permafrost thaw, and the effects of increased wildfire are not accounted for in many Earth System models or in some carbon budget approaches. This could reduce the remaining carbon budget further.[234,235]

239) AR6 WGI [236] gives remaining carbon budgets for selected values of global warming and for selected likelihoods of holding warming to these values. These budgets are reproduced in Table 5 below.

240) Large uncertainties could push these remaining carbon budgets higher or lower, though neglected or underestimated positive carbon feedbacks will always work to decrease carbon budgets.

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[234] Ciais P et al. (2013) Carbon and Other Biogeochemical Cycles, in Climate Change 2013: The Physical Science Basis, Fifth Assessment Report of the IPCC, edited by Stocker TF, et al., Cambridge University Press, pp. 465–570, doi:10.1017/CBO9781107415324.015.
[235] Steffen W et al. (2018) Trajectories of the Earth System in the Anthropocene. *Proc. Natl. Acad. Sci. (USA)* doi:10.1073/pnas.1810141115 and associated Appendix https://www.pnas.org/content/pnas/115/33/8252.full.pdf
[236] 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, Table SPM.2, accessed at: https://www.ipcc.ch/report/ar6/wg1/#SPM

Table 5: Remaining global carbon budgets *from 2020* as given by IPCC AR6 for various temperature limits and success likelihoods

Approximate global warming relative to the period 1850-1900 until the temperature limit (°C)	Estimated remaining carbon budgets from the **beginning of 2020** (Gt CO_2) *Likelihood of limiting global warming to temperature limit*				
Temperature Limit	17%	33%	50%	67%	83%
1.5	900	650	500	400	300
1.7	1450	1050	850	700	550
2.0	2300	1700	1350	1150	900

241) Notably, higher or lower reductions in accompanying non-CO_2 GHG emissions could alter the carbon budgets by 220 Gt CO_2 or more. In this context, however, it is important to note that **AR6 carbon budgets** in Table 5 **assume that non-CO_2 emissions are reduced sharply as well. Specifically, for methane, this implies at least a 30% reduction in 2030 compared with 2010, and a 50% reduction in 2050**.[237]

242) At the moment, **global methane emissions are rising, which means that remaining carbon budgets are shrinking**. In fact, since 2012, CH_4 emissions have been tracking the *warmest* scenarios assessed by the IPCC[238], and atmospheric concentrations have been rising at an increasing rate since about 2006 (refer to Fig. 5).

243) In order to establish the *remaining* carbon budgets from the beginning of 2022, the budget quantities in Table 2 must be reduced by the total CO_2 emissions released in 2020 and 2021, namely by about 80 Gt CO_2 (equivalent to 21.1 Gt C).[239]

244) **In this Report, I focus on carbon budgets that correspond to at least a 67% chance (two-in-three chance) of meeting the indicated temperature target**, noting that a 50% likelihood is equivalent to basing the most critical of environmental outcomes on the flip of a coin. Table 6 thus presents remaining carbon budgets from the beginning of 2022 for at least a 67% likelihood of limiting global warming to 1.5°C, 1.7°C and 2.0°C.

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[237] United Nations Environment Programme (2021). *Emissions Gap Report 2021: The Heat Is On – A World of Climate Promises Not Yet Delivered*. Nairobi. Accessed at: https://www.unep.org/resources/emissions-gap-report-2021
[238] Saunois, M. et al. (2020) The Global Methane Budget 2000 – 2017, Earth System Sci. Data, 12, 1561, https://doi.org/10.5194/essd-12-1561-2020
[239] Friedlingstein, P et al. (2021) Global Carbon Budget 2021, Earth Syst. Sci. Data https://essd.copernicus.org/preprints/essd-2021-386/

Table 6: Remaining global carbon budgets from 2022 for a 67% chance of holding warming to various temperature limits (rounded to the nearest 10 Gt CO_2)

Approximate global warming relative to the period 1850-1900 until the temperature limit	Paris Agreement Significance*	Estimated remaining carbon budget from the **beginning of 2022** ($GtCO_2$)
Temperature Limit		*67% likelihood of limiting global warming to temperature limit*
1.5 °C	Required Level of Effort	320
1.7 °C	Consistent	620
2.0 °C	Not Consistent	1070

245) In order to place these quantities in perspective, note that global annual emissions are now estimated to have rebounded from a small decline caused by COVID-19 restrictions, and now stand at about 40 Gt CO_2 per annum.[240] Thus, **only about 8 years remain at current emission levels before the remaining 1.5°C carbon budget** (from Table 6) **is exhausted**. **This is one of many ways to understand why the period until 2030 is so critical.**

246) A recent independent report[241] has reassessed Australia's emissions targets, using the carbon budget methodology used by the Government-established Australian Climate Change Authority (CCA) to arrive at its 2014[242] and 2015[243] recommendations for Australian GHG reduction targets, namely, a 40 – 60% reduction on 2000 levels by 2030. **The new report concludes that in order to be consistent with holding warming to 1.5°C with just a 50% chance, Australia's 2030 emissions reduction target must be 74% below 2005 levels, with net-zero emissions reached by 2035. This level of emissions reduction by 2030 is nearly three times that of Australia's Paris NDC**.

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[240] Friedlingstein, P et al. (2021) Global Carbon Budget 2021, Earth Syst. Sci. Data https://essd.copernicus.org/preprints/essd-2021-386/

[241] Hewson, J., Steffen, W., Hughes, L, and Meinshausen, M. (2021) Australia's Paris Agreement Pathways: Updating the Climate Change Authority's 2014 Emissions Reduction Targets, https://www.climatecollege.unimelb.edu.au/files/site1/docs/%5Bmi7%3Ami7uid%5D/ClimateTargetsPanelReport.pdf

[242] CCA (Climate Change Authority) (2014) Reducing Australia's Greenhouse Gas Emissions: Targets and Progress Review—Final Report, https://www.climatechangeauthority.gov.au/reviews/targets-and-progress-review-3

[243] CCA (Climate Change Authority) (2015) Final Report on Australia's Future Emissions Reduction Targets, https://www.climatechangeauthority.gov.au/sites/default/files/2020-07/Final-report-Australias-future-emissions-reduction-targets.pdf

7.3 The Fossil Fuel Production Gap

247) The primary reason why current global policies place the world on track for about 3°C of warming is that future fossil fuel production is not being curtailed quickly.

248) A 2021 special report by the **International Energy Agency (IEA)**[244] specifically designed for the **global energy sector** as a **roadmap** for achieving a net zero pathway (by 2050) listed (among other measures) **three significant milestones in the report's pathway that illustrate the scope of the changes required**:

a) **Beginning in 2021: No new oil and gas fields approved for development; no new coal mines or mine extensions; no new unabated coal plants approved for development.**

b) **By 2030: Phase-out of unabated coal in advanced economies.**

c) **By 2040: Phase-out of all unabated coal and oil power plants.**

249) A 2015 economic analysis **based on only a 50% chance of achieving 2°C** concluded that **a third of oil reserves,**[245] **half of gas reserves, and over 80% of coal reserves** (as defined in 2015) **must remain unused** from in the period from 2010 to 2050 **in order to meet a warming target of 2°C**, above Paris Agreement goals.[246]

250) Updating this work in 2021, a **new research** paper[247] estimates that in order to have **at least a 50% probability** of keeping the global temperature increase to about **1.5°C, 58% of oil, 59% of fossil methane gas, and 89% of coal reserves** (as identified in the 2018 reserve base) **must not be extracted**. This means that very high shares of reserves considered economic today cannot be extracted if the world is to meet a global warming target of 1.5 °C above pre-industrial temperatures.

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[244] IEA (2021) Net Zero by 2050: A Roadmap for the Global Energy Sector, accessed at: https://www.iea.org/reports/net-zero-by-2050

[245] Here, 'reserves' is taken to mean a subset of known resources that are defined to be recoverable under current economic conditions and have a specific probability of being produced.

[246] McGlade C and Ekins P (2015) The geographical distribution of fossil fuels unused when limiting global warming to 2°C. *Nature* 517: 187-190.

[247] Welsby, D, Price, J, Pye, S, and Elkins, P (2021) Unextractable fossil fuels in a 1.5C world, Nature, 597, Accessed at: https://www.nature.com/articles/s41586-021-03821-8

251) Underscoring this point are recent reports[248,249,250] that analyse the gap between different nations' expectations for the production of fossil fuels and the Paris Agreement warming target that the same nations support. The 2021 analysis shows that **governments are still planning to produce about 45% more fossil fuels by 2030 than would be consistent with a 2°C pathway and more than double than would be consistent with a 1.5°C pathway.**

252) **The disconnect between the intention to produce more fossil fuels and the simultaneous commitment to reduce emissions to meet the Paris Agreement has been called the `Production Gap.'** This Production Gap is illustrated in Fig. 26 below, taken from the latest Stockholm Environment Institute (SEI et al.) report.[251]

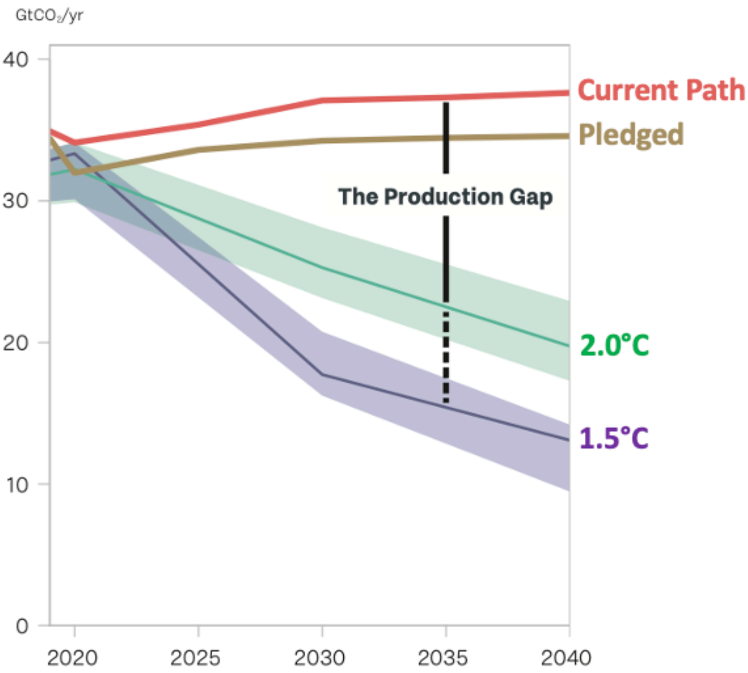

Fig. 26: Possible trajectories of global CO_2 emissions from all fossil fuels from 2019 to 2040 in units of $GtCO_2$ emitted in each year. In red is the current trajectory, whilst the gold line indicates what would be achieved if all Paris Agreement pledges were met. Lavender and turquoise trajectories reflect world fossil fuel production consistent with a 50% chance of holding warming to 1.5°C, or 66% chance of holding warming to 2.0°C, respectively. Shaded regions indicate uncertainty ranges for the 1.5°C and 2.0°C trajectories.

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[248] SEI, IISD, ODI, Climate Analytics, CICERO, and UNEP (2019) The Production Gap: The discrepancy between countries' planned fossil fuel production and global production levels consistent with limiting warming to 1.5°C or 2°C. https://productiongap.org/2019report/

[249] SEI, IISD, ODI, E3G, and UNEP (2020) The Production Gap Report: 2020 Special Report. https://productiongap.org/2020report/

[250] SEI, IISD, ODI, E3G, and UNEP (2021) The Production Gap Report: 2021 Report. Governments' planned fossil fuel production remains dangerously out of sync with Paris Agreement limits. https://productiongap.org/2021report/

[251] SEI, IISD, ODI, E3G, and UNEP (2021) The Production Gap Report: 2021 Report. https://productiongap.org/2021report/

253) The world is emitting about 36 Gt CO_2 per year from fossil fuels[252] (see Fig. 7). By 2030, this must *drop* to about 18 Gt CO_2 per year or 26 Gt CO_2 per year in order to hold warming to 1.5°C or 2°C, respectively (central estimates). Yet, current global policies associated with fossil fuel production are consistent with *increasing* the fossil CO_2 to at least 2040. In other words**, it is primarily the `overproduction' of fossil fuels that is preventing the world from being on-track to meeting a global warming limit of 1.5° – 2°C**.

254) **Furthermore, the production of *each* of coal, oil, and gas must drop immediately and sharply before 2030 to provide sufficiently significant cuts before 2030 for even a 50% chance of holding global warming to 1.5°C, according to the Production Gap Report. For a 66% chance of holding warming to 2°C, the report concludes that oil and gas production must fall after 2030, and coal production must steadily and quickly decline well before 2030.**[253] (See Fig. 27 below).

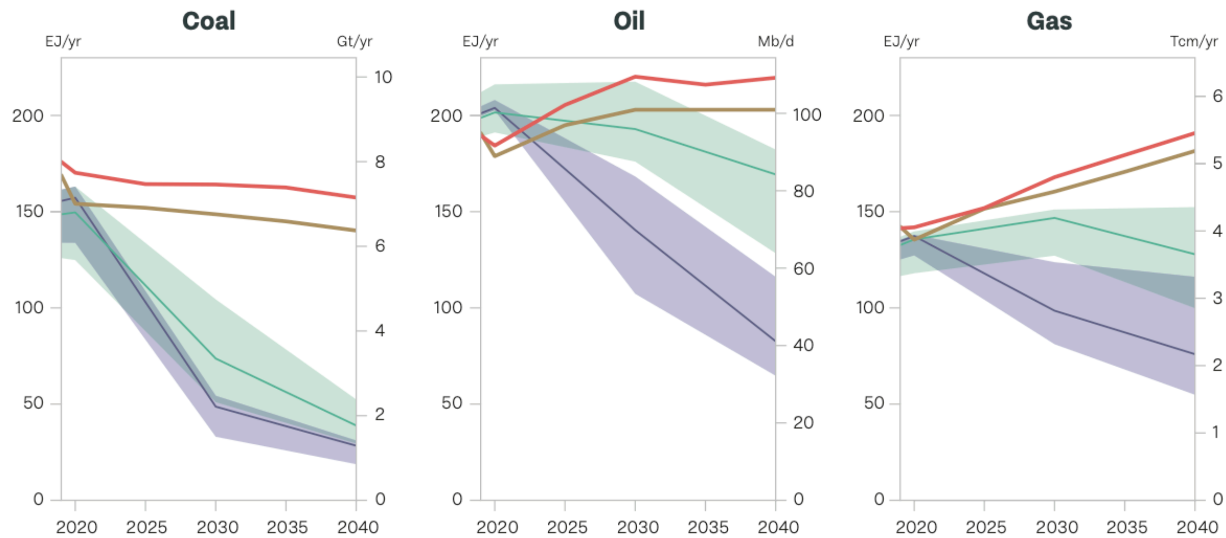

Fig. 27: Global emissions trajectories for coal, oil, and gas production based on current production and projections (red) and as implied by climate pledges (gold). Also shown is a range of trajectories consistent with holding global warming to 2.0°C with a 66% chance (light green), and with holding global warming to 1.5°C with 50% chance (lavender). From SEI et al. 2021.[254]

255) Redressing this fossil fuel production gap cannot be met by *adding* fossil fuel development, even that which may have already planned. Instead, **new fossil fuel**

[252] Friedlingstein, P et al. (2020) Global Carbon Budget 2020, Earth Syst. Sci. Data, 12, 3269-3340, https://doi.org/10.5194/essd-12-3269-2020 Table 6 on p3292 noting units there are GtC not $GtCO_2$.
[253]SEI, IISD, ODI, E3G, and UNEP (2021) The Production Gap Report: 2021 Report. https://productiongap.org/2021report/
[254]SEI, IISD, ODI, E3G, and UNEP (2021) The Production Gap Report: 2021 Report. https://productiongap.org/2021report/

development and expansion must cease, and ageing facilities brought to rapid close if global warming is to be halted at 1.5°C or even 2.0°C above pre-industrial times. The longer we wait, the more difficult the transition becomes.

7.3.1 Australia and the Production Gap

256) Australia's (and NSW's) effect on global warming and climate change goes far beyond its direct emissions (or Scope 1) of greenhouse gases. **Australia has a large indirect contribution to climate change through the emissions of countries that burn our nation's exported fossil fuels. These are part of Australia's 'Scope 3' emissions.**

257) Although the *National Greenhouse and Energy Reporting Act 2007* (the NGER Act)[255] does not require reporting of Scope 3 emissions for Australian entities, all emissions arising directly or indirectly from an activity lead to global warming and climate change, regardless of where they are emitted. Thus, **all emissions, including Scope 3 emissions** released when fossil fuels are combusted by any end user, **must be included when considering the effect on the climate of a given activity. To do otherwise is to assume that the fuel is never used for its intended purpose.**

258) **Australia is the world's second leading exporter of coal** (by weight)[256] **and the largest exporter of LNG.**[257] Australia's annual production of coal has risen sharply over the past decades, and then dropped slightly as brown coal production has decreased (see Fig. 28). Black coal production has approximately levelled over the past five years.

259) **As the world's fifth largest producer of coal, and world's largest exporter of black coal,**[258] **Australia has an enormous responsibility, and an enormous opportunity, to contribute to closing the Production Gap to a climate stabilised well below 2°C of warming compared to pre-industrial times.**

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[255] Accessed at: https://www.legislation.gov.au/Details/C2019C00044
[256] International Energy Agency (2021) Coal 2021 https://www.iea.org/reports/coal-2021
[257] International Gas Union (IGU 2021), 2021 World LNG Report. https://www.igu.org/resources/world-lng-report-2021/
[258] IEA data for 2019-2020 referenced by Geoscience Australia. Accessed at: https://www.ga.gov.au/digital-publication/aecr2021/coal#data-download-section

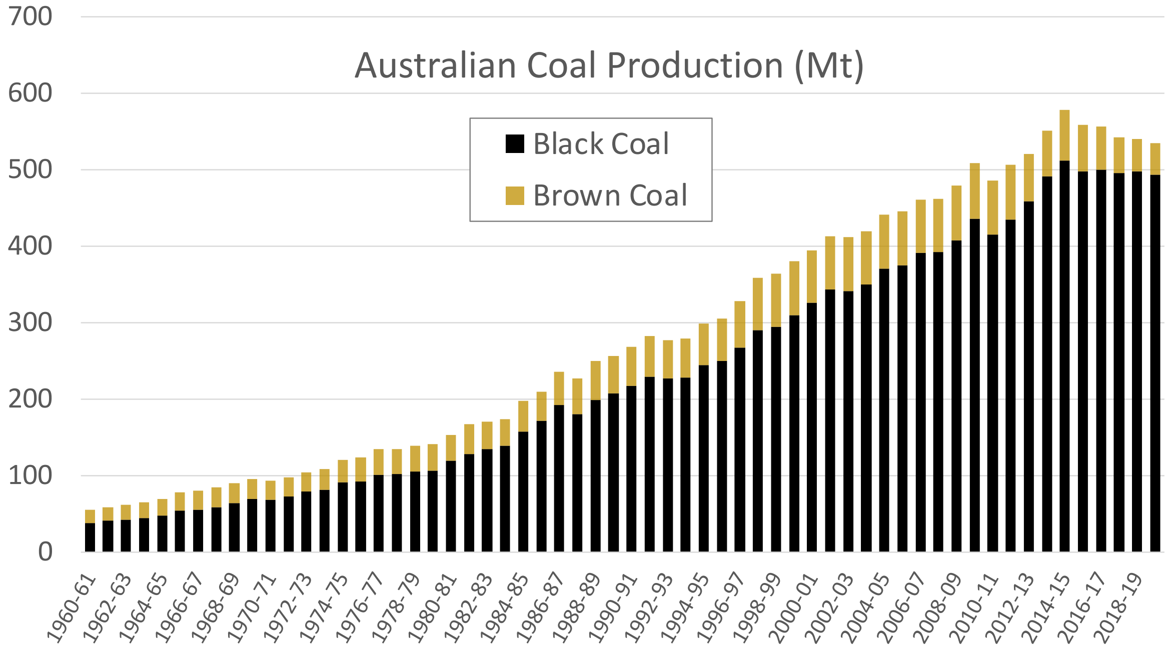

Fig. 28: Australia's production of brown and black coal (in Mt) is shown for every fiscal year from 1960-61 through 2019-20. Data are from Australian Government (2021) Australian Energy Statistics, Table P2, Dept of Industry, Science, Energy and Resources, September 2021. Total coal production is indicated by the total height of the bar in a given year. Data were accessed at: https://www.energy.gov.au/publications/australian-energy-update-2021

260) Despite this, the Commonwealth Government is anticipating steady coal production through 2030.[259] **Australian Government modelling published in 2021 anticipates (Scope 1 and 2) emissions from coal mining to remain constant over the period 2019 to 2030, implying that the total amount of coal extracted annually will stay approximately the same over this period.** Oil and gas extraction emissions, on the other hand, are projected to rise by 7% over the period.[260] **These forecasts are highly inconsistent with trends in coal, gas and oil production required to hold warming to 1.5°C, and for coal, highly inconsistent with even holding warming to 2.0°C** (see Fig. 27).

[259] Department of Industry, Science, Energy and Resources (2021) Australia's emissions projections 2021. See their Tables 8, 9, 15 and associated text. Accessed at: https://www.industry.gov.au/data-and-publications/australias-emissions-projections-2021

[260] Department of Industry, Science, Energy and Resources (2021) Australia's emissions projections 2021. See their Tables 8, 9, 15 and associated text. Accessed at: https://www.industry.gov.au/data-and-publications/australias-emissions-projections-2021

261) Recent international reports have analysed Australia's projections,[261,262] **concluding that Australia's extraction-based** (also called production-based) **emissions**[263] **from fossil fuel (coal and gas) production are expected to nearly double by 2030 compared to 2005 levels**, indicating that **Australia is a major contributor to the Production Gap**[264] **between global intended fossil fuel production and the Paris Agreement target for global warming**. In this sense, **Australia is indirectly working against global warming being held to 1.5°C (and even to 2.0°C), through the large Scope 3 emissions associated with its fossil fuel production, which is primarily for export**.

262) Comparison of the historical plot of coal production (Fig. 28) with the future trend in coal production required in order to hold global warming to between 1.5°C to 2.0°C (Fig. 27, left panel) reveals the **huge magnitude of reduction required if Australia is to align its coal production with Paris Agreement targets**.

263) **Recent analysis indicates that 95% of Australia's coal reserves**[265] **– and globally 89% of all coal reserves – must stay in the ground in order for the world to have a 50% chance of holding warming to 1.5°C**.[266]

264) So-called `committed emissions' from proposed or existing fossil fuel infrastructure is incompatible with holding warming to 1.5°C,[267] implying that **staying below 1.5°C may require governments and companies not only to cease licensing and development of**

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[261] SEI, IISD, ODI, Climate Analytics, CICERO, and UNEP. (2019). The Production Gap: The discrepancy between countries' planned fossil fuel production and global production levels consistent with limiting warming to 1.5°C or 2°C. http://productiongap.org/
[262] SEI, IISD, ODI, E3G, and UNEP. (2020). The Production Gap Report: 2020 Special Report. https://productiongap.org/2020report/
[263] `Extraction-based' emissions are part of a system of accounting that attributes greenhouse gas emissions from the burning of fossil fuels to the location of fuel extraction. It is an alternate, scientifically valid way to account for emissions.
[264] SEI, IISD, ODI, Climate Analytics, CICERO, and UNEP. (2019). The Production Gap: The discrepancy between countries' planned fossil fuel production and global production levels consistent with limiting warming to 1.5°C or 2°C. http://productiongap.org/
[265] Here, reserves is taken to mean coal that is technically and economically proven given market conditions at the time of study, which is 2018.
[266] Welsby, D, Price, J, Pye, S, and Elkins, P (2021) Unextractable fossil fuels in a 1.5C world, Nature, 597, Accessed at: https://www.nature.com/articles/s41586-021-03821-8
[267] Tong, D. et al. (2019), Committed emissions from existing energy infrastructure jeopardize 1.5 °C climate target, in Nature, 572, 373-7.

new fields and mines, but also to prematurely decommission a significant portion of those already developed.[268]

265) Yet, Australia has more capacity in export-oriented coal projects in the pipeline than any other country by far, as illustrated in Fig. 29 below, taken from a 2021 report of the IEA.[269] Australia also leads in the capacity of mine re-openings per country. [270] **Without changes to current plans, Australian coal exports will contribute to the global warming Production Gap, disproportionately so, for decades to come.**

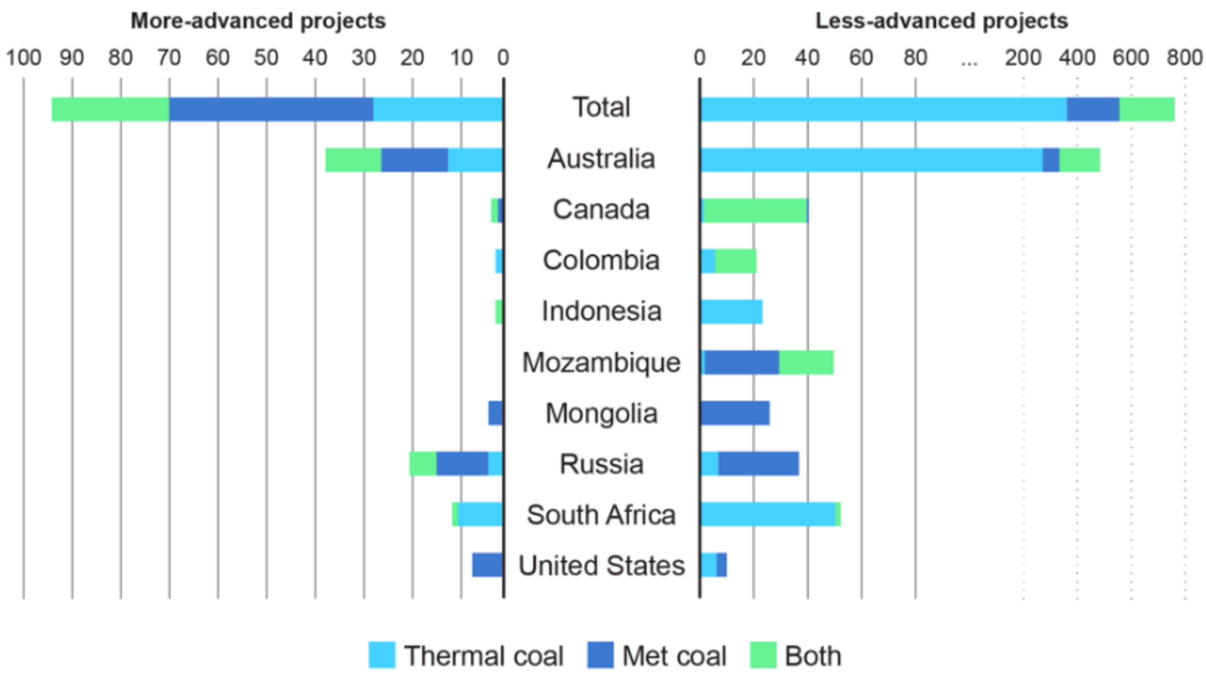

Fig. 29: Top countries by the capacity (measured in Mt of coal per annum) of new export projects for coal, as assessed by the IEA in 2021. `More-advanced' projects are those that have been approved and obtained a final investment decision or are under construction, while `less-advanced' projects are at the feasibility or environmental assessment stage, or they are awaiting approval. `Met' coal is metallurgical (or coking) coal.

266) GHG emissions arising from the burning of Australia's coal by end users (wherever that combustion may occur) are just as harmful to Australia's environment – on a tonne per tonne basis – than Scope 1 emissions arising within Australian borders.

267) In order to estimate the magnitude of the total effect, I have used the data displayed in Fig. 28 for coal production and the emission factors for different types of coal given in

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[268] Trout, K. et al. (2022) Existing fossil fuel extraction would warm the world beyond 1.5°C, in Environ. Res. Letters, 17, 064010.
[269] International Energy Agency (2021) Coal 2021 https://www.iea.org/reports/coal-2021
[270] International Energy Agency (2021) Coal 2021 https://www.iea.org/reports/coal-2021

the National Greenhouse Accounts Factors.[271] As there are different grades of black coal, I have used sub-bituminous coal to give a lower estimate (1.895 tCO_2-e/t coal) and coking coal to give an upper estimate (2.761 tCO_2-e/t coal) for Australia's black coal production. Brown coal is assumed to have an emission factor of 0.957 tCO_2-e/t coal. The results are shown in Fig. 30 below.

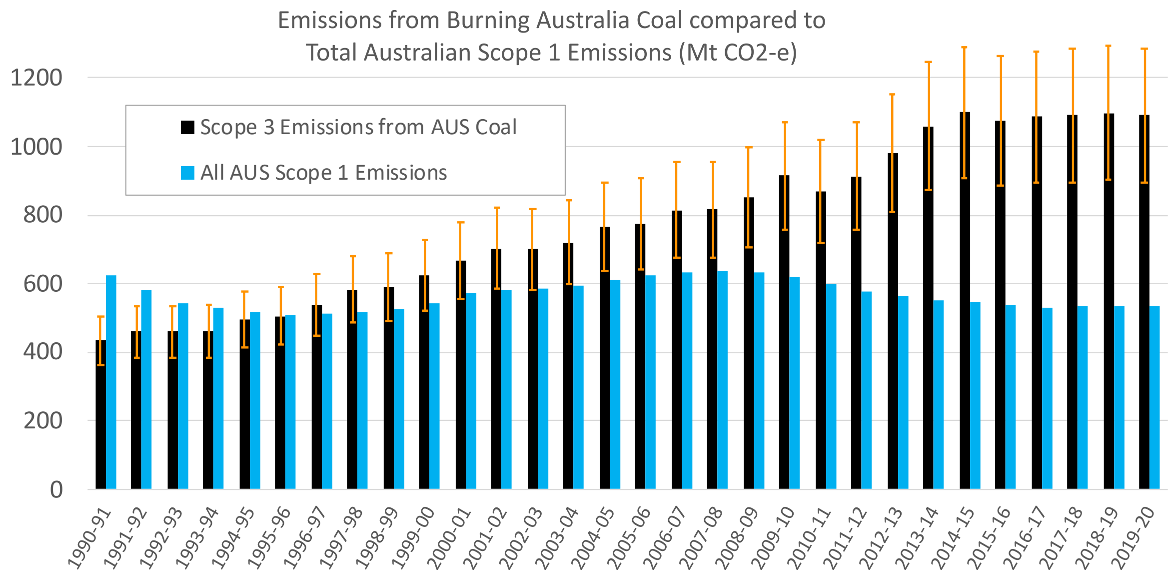

Fig. 30: Estimated emissions from the burning of Australian coal by the end user (black) compared to the total of all Australia's territorial (Scope 1) emissions (blue) over the period 1990 to 2019. The orange bars indicate the wide range of assumptions about the emissions intensity of Australia black coal (see text).

268) As Fig. 30 shows, **over the past five years, GHG emissions from the burning of Australia coal have** been twice that of all GHG emissions directly emitted by Australians in those years, having therefore, **twice the detrimental effect on the Australian environment as do all the emissions emitted directly by Australians from all other activities within the national borders.**

7.3.2 New South Wales and the Production Gap

269) NSW is central to closing Australia's Production Gap (see Section 7.3.1) in order to meet the Paris Agreement warming target and avoid the devastating climate impacts at 2°C of warming or more. Despite this, coal production in NSW, one of Australia's two largest black coal-producing States, shows no sign yet of declining.

[271] Australian Government (2021) National Greenhouse Accounts Factors. See their Table 1.

270) In 2019-20, production of black coal in Australia fell slightly from its all-time peak the year before, but the production in NSW continued to grow.[272] The trend in annual production of black coal NSW is shown in Fig. 31. Comparison of this historical plot with the future trend in coal production required in order to hold global warming to between 1.5°C to 2.0°C (see Fig. 27, left panel) shows the **huge magnitude of reduction required if NSW is to align its production with Paris Agreement targets**.

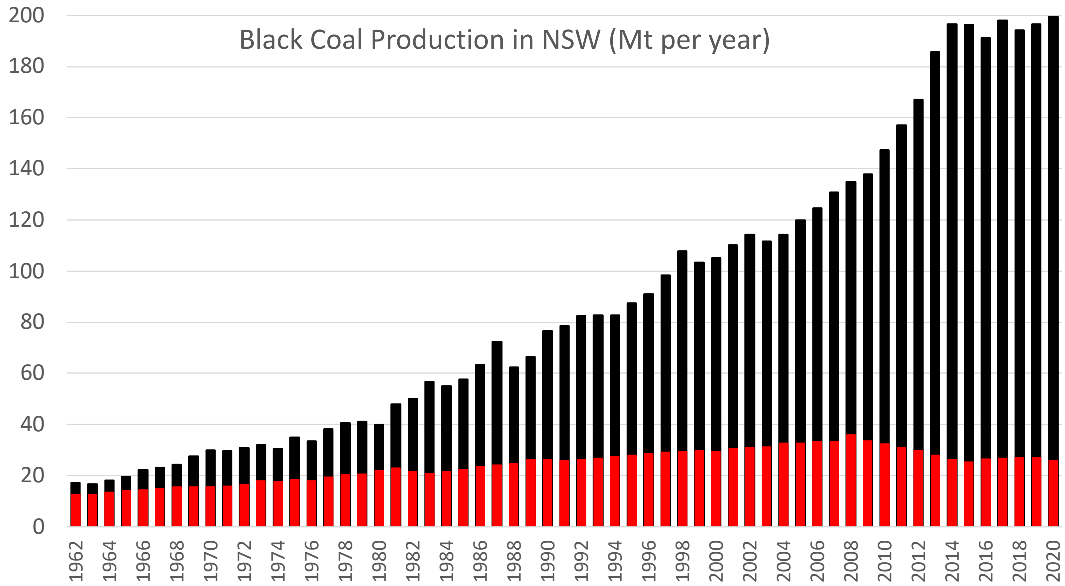

Fig. 31: NSW black coal production in thousands of tonnes (Kt) from 1960-61 to 2018-19. In red is the part of this black coal that is consumed in New South Wales in each year. Data are from Table I4 of Australian Energy Statistics 2021.

271) Cumulatively, over the past six decades, NSW has produced 5.0 billion tonnes (Gt) of black coal.[273] Using a carbon content of typical bituminous coal,[274] this is equivalent to about 12.2 Gt CO_2 due to combustion at its final destination, or about 0.88% of the world's total CO_2 emissions from fossil fuels and cement production over this time,[275] despite NSW accounting for only about 0.10% of the world's population.

[272] Australian Government (2021) Australian Energy Statistics, including Table I4, Dept of Industry, Science, Energy and Resources, September 2021. Accessed at: https://www.energy.gov.au/publications/australian-energy-update-2021
[273] Australian Government (2021) Australian Energy Statistics, including Table I4, Dept of Industry, Science, Energy and Resources, September 2021. Accessed at: https://www.energy.gov.au/publications/australian-energy-update-2021https://www.energy.gov.au/publications/australian-energy-update-2021
[274] Australian Government (2021) National Greenhouse Accounts Factors. See their Table 1.
[275] Using data downloaded from https://ourworldindata.org/co2-emissions

272) **In the ten years 2011 to 2020, the average *annual* production of NSW black coal has been responsible, when combusted, for about 459 Mt CO_2-e released into the atmosphere every year. These Scope 3 emissions from black coal combustion are over three times the State's entire average Scope 1 annual CO_2-e emissions over the same period**. On a per tonne basis, these Scope 3 emissions have an identical effect on NSW's future climate as do the Scope 1 emissions, yet the total amount is three times larger.

273) **As a result, NSW is a major contributor to the Production Gap**[276] between global intended fossil fuel production and the Paris Agreement agreed warming target range. In this sense, **NSW is indirectly working against global warming being held to 1.5°C (and even to 2.0°C), through the large Scope 3 emissions associated with its black coal production, primarily for export**. **Any new or expanded fossil fuel development in the State, including the Dendrobium SSI Project, will aggravate this situation.**

[276] SEI, IISD, ODI, Climate Analytics, CICERO, and UNEP. (2019). The Production Gap: The discrepancy between countries' planned fossil fuel production and global production levels consistent with limiting warming to 1.5°C or 2°C. http://productiongap.org/

8 The Dendrobium SSI Project and Climate Change

274) Greenhouse gases are a pollutant released into the atmosphere, most of which are well-mixed on relatively short time scales with global GHGs released from other human activities. The **cumulative effect of these GHGs causes climate change, and climate damages and risks to the people and environment of NSW.** Furthermore**, the cumulative effects are maintained for decades, centuries and millennia.** It is therefore **appropriate and in fact necessary,** in my view, **to consider the cumulative effect of GHGs when assessing the impact of the Project.**

275) In this section of the Report, I place the GHG emissions from the Project into a larger context that recognises their cumulative effect on climate change, by providing an analysis that considers:

a) why the Project is inconsistent with holding global warming well below 2°C,

b) how the Project (and recently-approved NSW coal projects) works specifically against NSW closing its coal `production gap' to such a climate,

c) the effect of the Project's fugitive emissions over a 20-year (rather than 100-year) timescale, comparable to the lifetime of the mine and NSW climate targets,

d) special climate-related risks to water availability and safety in Sydney's drinking water catchment,

e) implications of GHG emissions from the Project on the ability of the nation and NSW to meet their respective GHG targets, and

f) the effect of all GHG emissions derived directly, or indirectly, from the Project (i.e., Scopes 1, 2 and 3), given that on a tonne-per-tonne basis they affect the climate of NSW equally.

8.1 Approving the Project is Inconsistent with Warming well below 2°C

276) The phrase 'well below 2°C' is widely known to be associated with the UNFCCC Paris Agreement[277] commits signatories to "**keeping a global temperature rise this century well below 2°C above pre-industrial levels** and to pursue efforts to limit the temperature increase even further to 1.5°C." But this would be **the scientifically advisable goal whether the Paris Agreement existed or not, because (a) it is still achievable from a carbon budget point of view** (see Section 7.2) **and (b) temperatures of 2.0°C and above are associated with grave consequences and compounding risks to ecosystems and humans** (see Section 6.2).

277) **The most important step to achieving this goal is to dramatically reduce the production of fossils fuels – the overwhelming cause of anthropogenic climate change** (see Section 34). **The deepest and swiftest reduction must occur in coal production** (see Fig. 27, left panel), which must drop worldwide by a minimum 67% between 2020 and 2030 for a flip-of-coin chance (50%) of holding warming to 1.5°C.[278] Coal production must drop by a minimum of 36% in this period to hold warming to 2°C (with a 67% chance). Consequently, **to hold warming to well below 2°C, coal production must drop by *considerably more* than 36% on 2020 levels by 2030, which is less than 8 years away**.

278) **Simply put, approving new coal mines or extensions to existing ones, such as the Dendrobium SSI Project, is not consistent with holding warming to 2°C, let alone warming *well below* 2°C.**

279) In 2020, NSW mined 200 Mt of black coal.[279] **In order to align its production with the requirements for a trajectory consistent with holding warming well below 2°C**, **NSW must cut production by** about 50% (chosen to be intermediate between the minimum amounts for 1.5°C and 2.0°C quoted in paragraph 277) on 2020 levels by 2030, requiring a

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[277] UN (2015), Paris Agreement, Accessed from https://unfccc.int/sites/default/files/english_paris_agreement.pdf

[278] SEI, IISD, ODI, E3G, and UNEP (2021) The Production Gap Report: 2021 Report, using data provided in Supplementary Information. https://productiongap.org/2021report/

[279] Australian Government (2021) Australian Energy Statistics, including Table I4, Dept of Industry, Science, Energy and Resources, September 2021. Accessed at: https://www.energy.gov.au/publications/australian-energy-update-2021

new reduction of **about 11.1 Mt coal per annum from 2022 through 2030** (assuming 2021 levels were similar to those in 2020). This would result in the `well-below 2°C' profile shown in Fig. 32 below.

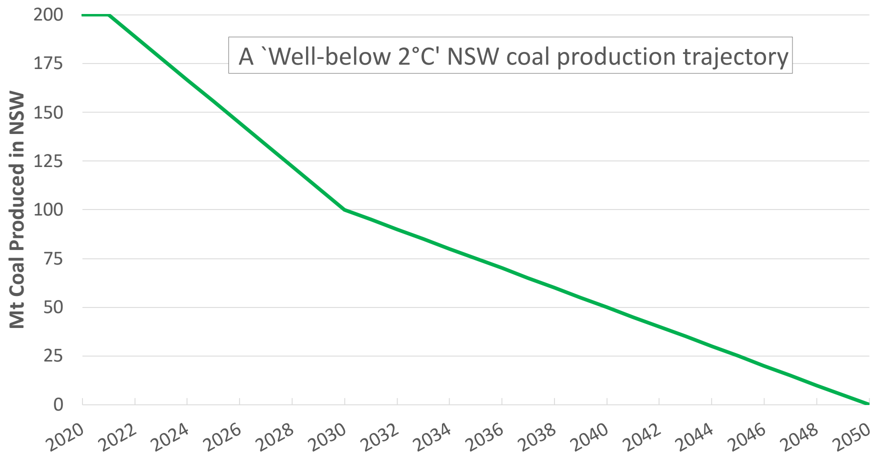

Fig. 32: A simple linear model in order for NSW to close its coal Production Gap in a manner consistent with the Paris Agreement warming goals, namely well-below 2°C (green).

280) **Over this period to 2030, the Project, if approved, would be *adding* about 1.45 Mt product coal (**1.67 Mt ROM coal) per annum on average[280] **to NSW's Production Gap.** This size of this effect is illustrated in Fig. 33, showing that over the primary years of production the Project would produce coal at about one-third the rate required for NSW to *reduce* its coal output consistent with the Paris Agreement warming target of well-below 2.0°C.

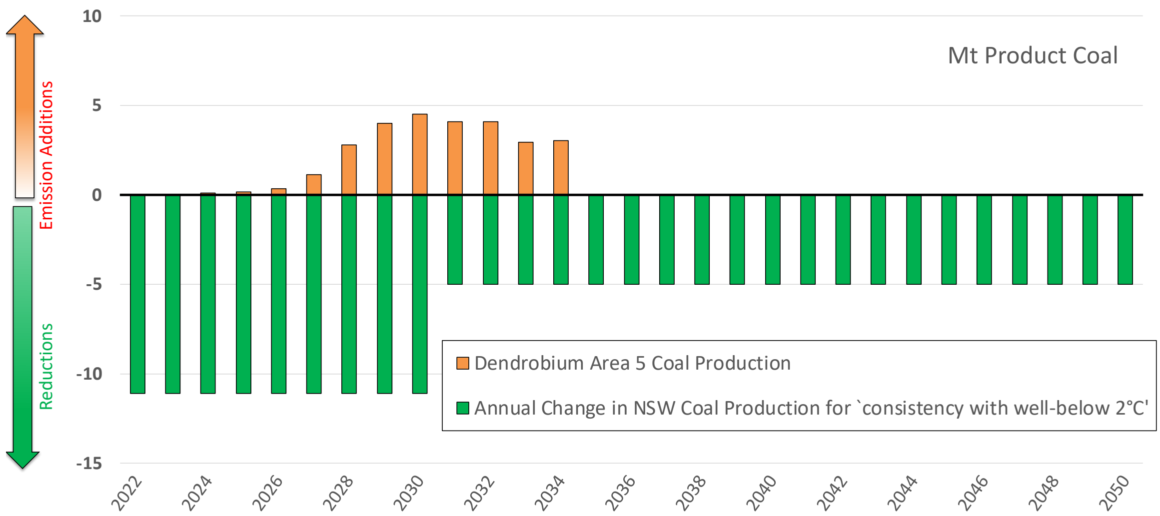

Fig. 33: Annual coal production from Dendrobium SSI Project (orange) compared to the annual reductions necessary in a simple linear model in order for NSW to close its coal Production Gap in a manner consistent with the Paris Agreement warming goals, namely well-below 2°C (green).

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[280] Using ROM amounts giving in the Applicant's Indicative Mining Schedule, reproduced as Fig. 8 of this Report, and multiplying by a factor 0.87 to derive Product coal. The factor 0.87 is based on Product/ROM ratios in years when most to all of the Product coal would be produced from Area 5.

281) Furthermore, closing NSW's coal production gap will need to take place against background of other recently approved coal development projects in NSW that themselves are adding to the future coal production trajectory of the State. Some of these projects[281] are listed in Table 7 below.

Table 7: Recently approved coal development projects in NSW.

Approved Project	Proponent	Consent Until	Maximum ROM Coal per annum (Mt)
Mangoola Continued Operations	Mangoola Coal Operations Pty Ltd	31 Dec 2030	13.5
Maxwell Underground	Maxwell Ventures (Management) Pty Ltd	30 Jun 2047	8.0
Narrabri	Narrabri Coal Operations Pty Ltd	31 December 2044	11.0
Rix's Creek South	Bloomfield Collieries Pty Ltd	12 Oct 2040	3.6
Russell Vale Underground Expansion	Wollongong Coal Ltd	5 years from commencement	1.2
Tahmoor South	Tahmoor Coal Pty Ltd	31 Dec 2033	4.0
United Wambo	United Collieries Pty Limited	21 Aug 2042	10.0
Vickery Extension Project	Vickery Coal Pty Ltd	12 Aug 2045	10.0
TOTAL			**61.3**

282) Although the numbers in the rightmost column of Table 7 are for maximum allowed run-of-the-mine (ROM) takes, these data make clear that **recently approved coal mine operations alone could be adding on the order of 30 – 40 Mt product coal annually to the State's production over a period in which *new reductions* of about 11 Mt per year from 2022 through 2030 is needed to be consistent with warming well below 2°C**. **Approving the Project would increase NSW production over this period still further.** Furthermore, the Project, like most of those in Table 7, will run beyond 2030, confounding later efforts to reduce coal production in line with warming well below 2°C.

283) In my opinion, **the recent approval of new or extended coal production in NSW has been inconsistent to holding warming to well-below 2°C, and continuing this trend with the approval of the Project adds more fuel to this fire.** Further, **it would be difficult to**

[281] All data from NSW IPC website at: https://www.ipcn.nsw.gov.au/projects

reconcile with the spirit of NSW's stated intent to reach net zero by 2050,[282] **given the advice of the IEA** (see paragraph 248) **that beginning in 2021, no new oil and gas fields should be approved for development, nor new coal mines or mine extensions** for consistency with its Net Zero by 2050 plan for the global energy sector.

8.1.1 The Special Role of Methane in Fuelling Climate Change

284) All coal seams contain some level of gas; these gases escape (become 'fugitive') during both open-cut and underground mining operations. These gases yield no economic benefit. **In 2019, reported fugitive methane emissions from coal mining in NSW were nearly equal to 80% of all methane emissions from agriculture in the state**, as illustrated in Fig. 34, in which agricultural CH_4 emissions are shown in green and fugitive coal mining CH_4 emissions in black.

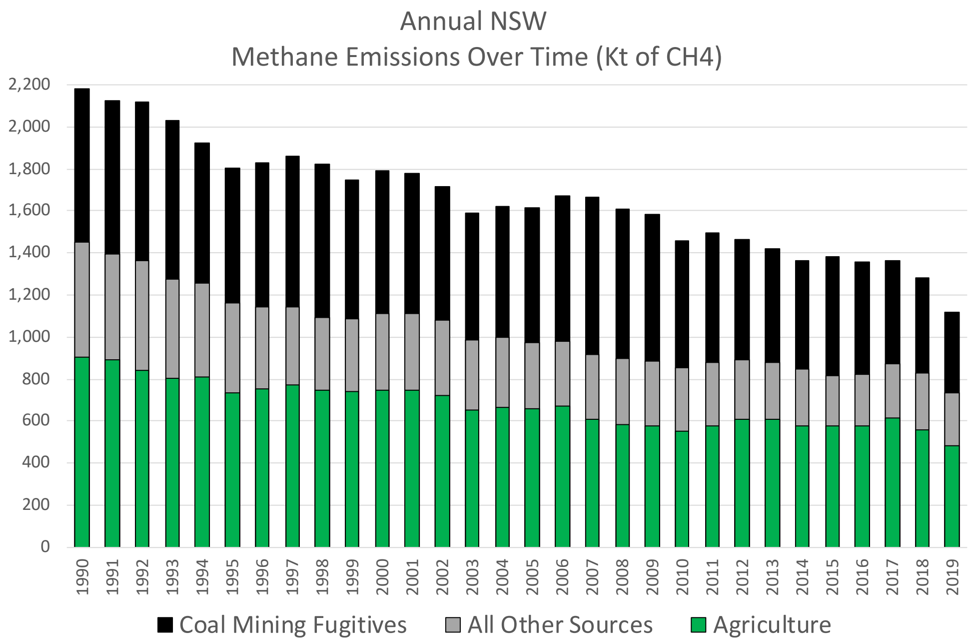

Fig. 34: Trend in annual New South Wales methane (CH_4) emissions from agriculture (green), fugitive emissions from coal mining (black), and all other sources (grey). Data are taken from the National Greenhouse Gas Inventory; units are kilotonnes of methane (Kt CH_4).

[282] NSW Government (2021) Net Zero Plan Stage 1: 2020-30 Implementation Update. Accessed at: https://www.environment.nsw.gov.au/research-and-publications/publications-search/net-zero-plan-stage-1-2020-30-implementation-update

285) It is noted that there is evidence[283], including from the IEA, that fugitive emissions from Australian coal mining is larger than reported, so that it is possible that fugitive methane emissions from coal in NSW may be considerably higher than shown in Fig. 34. In particular, **the IEA estimates[284] that Australian coal mines emitted 1754 Mt of methane in 2021, compared to 898 Mt reported in the National Greenhouse Gas Inventory (NGGI) for 2019,[285] almost twice as much.**

286) As discussed earlier (see paragraph 77), **fossil methane** (CH_4) **is a particularly potent GHG**, which according to the AR6 WGI has a global warming potential of 29.8 (compared to the GWP of 1 for CO_2) over 100-year timescales. **For 20-year timescales, relevant for judging the climate impact of the Project in NSW, the GWP of fossil CH_4 is 82.5**, compared to 1 for CO_2.[286]

287) Current **NGER regulations,[287] however, require GHG reporting to use GWP values of: 1, 28 and 265 for CO_2, CH_4, and N_2O, respectively,** coinciding with the most recent publication *National Greenhouse Accounts (NGA) Factors* 2018,[288] as the EIS GHG Estimates for the Project has done. **This leads to a severe underestimate of the effect of the Project on climate change over the Project lifetime of just under 20 years**.

288) Even if pre- and post- gas drainage is flared, mine ventilation air (MVA) is expected to account for 7,445,451 tonnes of CO_2-e over the lifetime of the mine, according to Table 8-6 of EIS Appendix I. Assuming that these GHG emissions are dominated by CH_4, and recalling that the EIS uses a GWP of 28 for CH_4, this is equivalent to 265,909 tonnes of fossil methane.

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[283] Ember (2022) Tackling Australia's Coal Mine Methane Problem, Accessed at: https://ember-climate.org/insights/research/tackling-australias-coal-mine-methane-problem/

[284] https://www.iea.org/articles/methane-tracker-data-explorer#total-comparison-sources

[285] https://ageis.climatechange.gov.au/

[286] Forster P., T. et al. (2021) The Earth's energy budget, climate feedbacks, and climate sensitivity, Chapter & of Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Table 7.15, accessed at: https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/

[287] See Division 2, Section 7 of https://www.legislation.gov.au/Details/F2020C00673

[288] Department of Industry, Science, Energy and Resources (August 2021) National Greenhouse Account Factors. Accessed at: https://www.industry.gov.au/data-and-publications/national-greenhouse-accounts-factors-2021

289) **Thus, on 20-year times scales, Project fugitive GHGs alone would have an effect on the climate equivalent to 21.9 Mt of CO_2, almost precisely double all the Scope 1 emissions quoted for the Project over its lifetime** (see Table 2). **If flaring of pre- and post-drainage gas is not undertaken, this number rises to the equivalent of 31.7 Mt of CO_2**. Furthermore, this does not include post-mining fugitives which would, in principle, continue indefinitely.

8.2 Climate Change and the Sydney Drinking Water Catchment

290) My field of expertise is not in water catchment considerations, so I cannot comment directly on the Project's effect on or risk to Sydney's drinking water. However, I can make a few remarks on the possible effects of and risks posed by climate change on water in the general catchment area for Sydney's drinking water,[289] which is shown in Fig. 35 below.

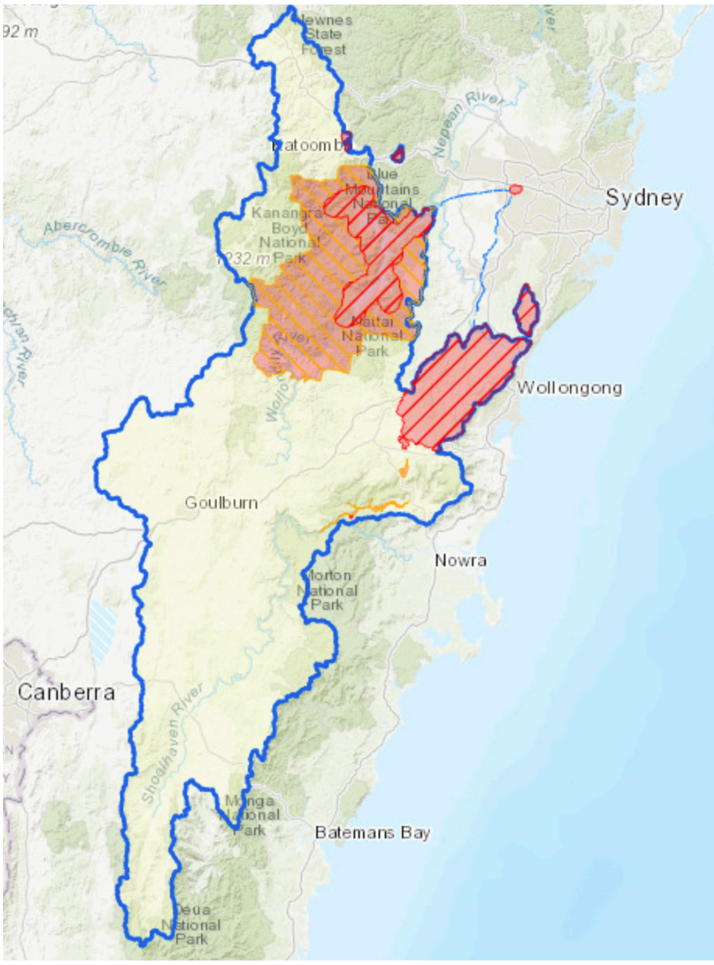

Fig. 35: Sydney's drinking water catchment is outlined in blue, with the inner catchment regions highlighted in pink. Red hashed areas indicate Schedule 1 Special Areas, where entry by the public is not allowed.

Figure is from WaterNSW.

[289] https://www.waternsw.com.au/water-quality/catchment/catchment-map

291) As noted in Section 6.2, **due to climate change, rainfall is expected to come in shorter, more intense bursts in the future, increasing the risk of flooding. Floods can affect drinking water supplies**, increasing the likelihood of contamination and closure of water treatment plants,[290] as was the case in the southeast Queensland earlier this year.

292) Overall, **climate change is expected to reduce runoff water by 15% in NSW for every degree of warming** (see paragraph 215)), though actual impacts will vary geographically over the state. **Nearly all of Sydney's drinking water catchment is likely to experience some reduced runoff in future, with the area immediately surrounding the Project likely to experience reductions of more than 30 mm per year by 2085, in an `intermediate' emissions reduction projection** (see Fig. 21)**.**

293) **Bushfire weather in NSW is expected to become more severe in future** (see Section 6.2.4), **with increased risk of contamination from ash making its way into the water supply, and conditions conducive to increased fish kills and algal growth.** Furthermore, **as bushfire risk increases in drought and heat waves, water resources are likely to already be stretched prior to the worst bushfires.**

294) The NSW Environment Protection Authority (NSW EPA) states that "*Fire increases the potential for runoff and erosion. Debris flows are erosion events that sometimes occur after fire, involving a fast-moving mass of unconsolidated, saturated debris. The sediment runoff following fires carries high levels of ash and charcoal that immediately impacts water quality."* . . . "*Bushfires can also disrupt power supply and destroy water infrastructure such as pumping stations and treatment plants, resulting in water quality impacts and supply disruption*." [291] **Drinking water catchments are particularly singled out by the NSW EPA as a priority area for minimising impacts and risks to bushfire contamination.**

295) **The bushfires of 2003 severely impacted the primary water catchment for the ACT, the Cotter. Before the fire, 96% of the water used by Canberra and Queanbeyan came**

[290] Wright, I. (2022) Drinking water can be a dangerous cocktail for people in flood areas, in The Conversation 28 Feb 2022. Accessed at: https://theconversation.com/drinking-water-can-be-a-dangerous-cocktail-for-people-in-flood-areas-178028

[291] NSW Environment Protection Agency (2020) Bushfire Impacts on Water Quality. Accessed at: https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/water/20p2093-bushfire-impacts-on-water-quality.pdf

from the Cotter. The fires burnt all the undergrowth in the Cotter catchment with 35% suffering a high-severity burn. **Intense rain a few weeks later washed silt and debris into one of the reservoirs, and the Cotter water supply was closed for about six months, which placed alternate sources under severe stress, necessitating water restrictions.** It is estimated that the erosion from one rainfall event after the 2003 bushfires created more erosion in the catchment than had occurred for about 400 years.[292]

296) **The Black Summer fires created water quality issues throughout the Bega valley**, as facilities responsible for disinfecting the drinking water went offline, requiring residents to boil all water.[293] **Heavy rain on Sydney's largest drinking water catchment** – the Warragamba – **shortly after the Black Summer bushfires**, **generated severe concerns around impact that bushfire ash and run-off** from the damaged catchment **into the Warragamba Dam would have on water quality, necessitating alternate sources for Sydney to be found.**[294]

297) Increased climatic risk of flooding in future also increases the risk of contamination to water supplies due to release of toxic mine water, as occurred during Queensland floods in 2013.[295]

8.3 Implications of the Project for National and State Emissions Targets

298) **Comparisons to current emissions or to emissions targets set by governments in a given year are often used as a proxy for assessing climate change impact.** Such comparisons are an **imperfect and often misleading measure for climate impact assessments** because:

a) **Current levels of emissions are already causing dangerous levels of climate change**,

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[292] Davidson, S. (2004) Burning Issues for Water Supplies, CSIRO ECOS, 120, 8. Accessed at: http://www.ecosmagazine.com/?paper=EC120p8

[293] See e.g., https://begavalley.nsw.gov.au/council/important-water-quality-advice

[294] WaterNSW (2020) Bushfire inquiry commends WaterNSW for protection of catchment and water quality Accessed at: https://www.waternsw.com.au/about/newsroom/2020/bushfire-inquiry-commends-waternsw-for-protection-of-catchment-and-water-quality

[295] Heber, A. (2013) Toxic mine water released during QLD flooding, in Australian Mining, 30 Jan 2013, Accessed at: https://www.australianmining.com.au/news/toxic-mine-water-released-during-qld-flooding/

b) **Emission targets may not reflect the actual speed, magnitude or risk of climate change**,

c) Regional targets that count only regional (Scope 1, or Scope 1 + Scope 2) emissions, **ignore the real consequences of any Scope 3 emissions** from local activities on local climate, and

d) **A similar argument could be made for any number of projects, whose cumulative effect would then exceed the intent of setting the target in the first place**.

299) Nevertheless, comparing Project emissions to NSW and national GHG targets is an important step in guiding action to meet those targets.

300) **NSW has committed to achieving zero net emissions by 2050, with an interim target to reduce emissions by 50% below 2005 levels by 2030,** representing a considerable increase in ambition from its previous 2030 target of 35% reduction.[296]

301) **Australia has committed to achieving zero net emissions by 2050**[297]**, and formally (through the Paris Agreement) to reduce its emissions by 26% – 28% by 2030** on 2005 levels.[298] **The current Labor Government has increased this ambition to a 43% reduction**[299] **by 2030 on 2005 levels, which will be used throughout this section of the Report**.

302) **In order to achieve a 50% reduction on state 2005 GHG emissions**, which were 165 Mt CO_2-e, **NSW's emissions in 2030** must be no more than 83 Mt CO_2-e, **requiring a considerable drop from its current emissions**.

303) **In order to achieve a 43% reduction on national 2005 GHG emissions**, which were 642 Mt CO_2-e, **Australia's emissions in 2030** must be no more than 356 Mt CO_2-e, **also requiring a significant drop from current emissions.**

[296] NSW Government (2021) Net Zero Plan Stage 1: 2020-30 Implementation Update. Accessed at: https://www.environment.nsw.gov.au/research-and-publications/publications-search/net-zero-plan-stage-1-2020-30-implementation-update

[297] See, e.g. https://www.pm.gov.au/media/australias-plan-reach-our-net-zero-target-2050

[298] Commonwealth of Australia, Australia's 2030 Emissions Reduction Target Fact Sheet, https://pmc.gov.au/sites/default/files/publications/fact_sheet-aus_2030_climate_change_target.pdf

[299] See, e.g., https://www.alp.org.au/policies/powering-australia

304) **Based on EIS GHG Estimates** (see Table 2 of this Report, which contains self-consistent summary statistics) **average annual Scope 1 and Scope 2 GHG emissions from the Project over the life of the mine would be about 0.609 Mt CO_2-e and 0.065 Mt CO2-e, respectively**. Together, this **corresponds to about 0.13% and 0.49% of Australia's and NSW's total emissions in 2019, respectively**. However, as NSW and Australia (presumably) meet their 2030 emissions target and begin to approach net zero by 2050, the Project will form a higher percentage of the State's and country's annual emissions.

305) Figure 36 compares the notional emissions Scope 1 + Scope emissions trajectory of the Project with simple linear trajectories for NSW and Australia that meet their current respective Government's GHG reduction targets for 2030 (50% for NSW and 43% for the Commonwealth on 2005 levels) as well as net zero by 2050. **Despite the apparently small contribution of the Project compared to the emissions trajectory of NSW, I show in what follows the negative effects the GHG emissions of the Project would have on the ability of the country and the State to meet 2030 emissions targets.**

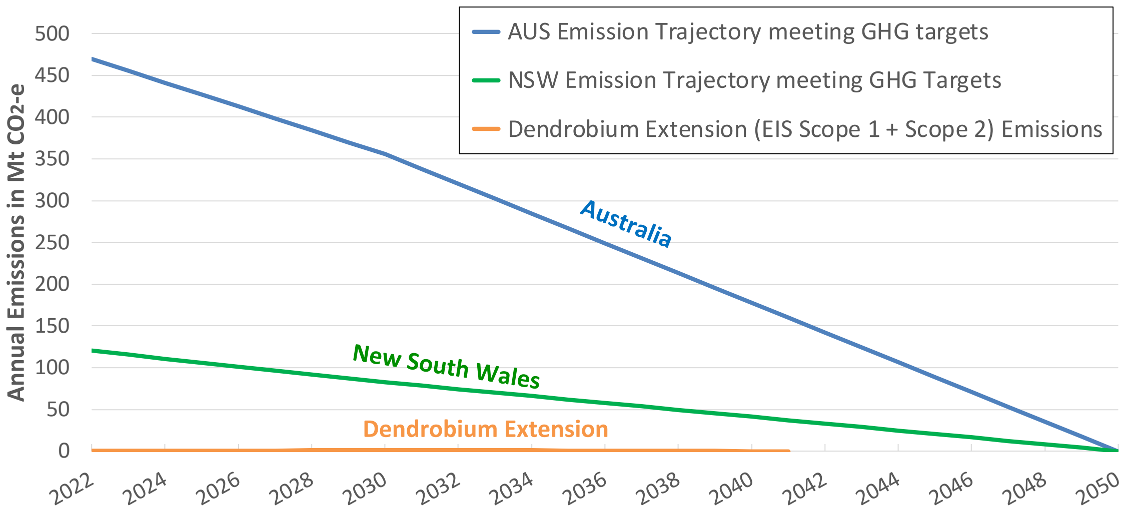

Fig. 36: Comparison of a simple (linearly-falling) emissions trajectories for Australia (blue) and NSW (green) that meet their respective GHG targets and the assumed Scope 1 + Scope 2 emissions trajectory of the Dendrobium SSI Project (orange). The effect of the Project is larger than a cursory examination of these trajectories might seem to imply, as shown in Fig. 37.

306) The starting point for the national and NSW trajectories shown in Fig. 36 is based on the most recent values (2019) values from the NGGI[300] at the time of writing of this Report, adjusted for estimated reductions based on COVID restrictions, namely that 2020 and

[300] https://ageis.climatechange.gov.au/

2021 CO_2-e emissions will be 88.9% and 91.5%, respectively, of those in 2019. These assumptions are based on global changes in CO_2 (only) emissions in 2020 and 2021.[301, 302]

307) **A more relevant measure than comparing GHG emissions to state and national totals is to compare the annual Scope 1 + Scope 2 emissions from the Project to the annual emissions *reduction* required in order for Australia and NSW to meet their 2030 targets.** The Australian 2030 target, if approached linearly, requires an average *new reduction* of 14.25 $MtCO_2$-e per year, year on year, from 2022 up to and including 2030. In other words, to meet its promised new 2030 Paris NDC, Australia will need to not only maintain its reduction from the previous years, but find another *further reduction* of 14.25 $MtCO_2$-e each year through 2030. Similarly, NSW will have to find an average *new reduction* of 4.71 $MtCO_2$-e per year, year on year, from 2022 up to and including 2030. Fig. 37 illustrates the size of these NSW reductions compared to Scope 1 and Scope 2 emissions from the Project.

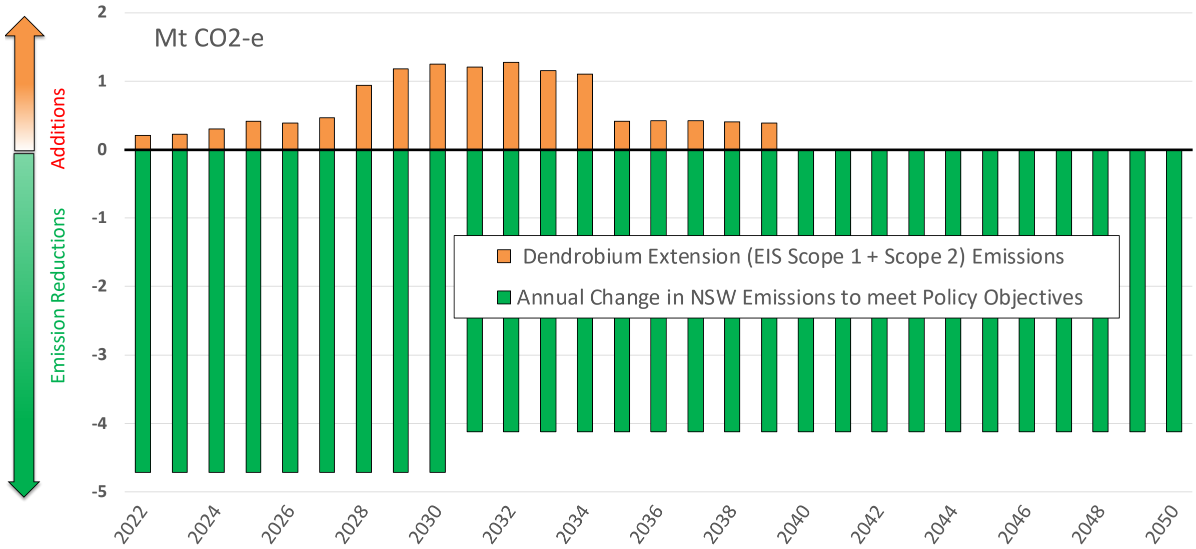

Fig. 37: Size of annual Scope 1 + Scope 2 emissions from the Project (orange) compared to the annual reductions necessary in a simple model in order for New South Wales to meet both its stated 2030 and 2050 targets in the linear fashion (green).

308) **The Dendrobium SSI Extension Project is quite significant compared to the annual task in meeting NSW's GHG targets, both before and after 2030. In each of the years**

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[301] Friedlingstein, P. et al. (2020) Global Carbon Budget 2020, Earth Syst. Sci. Data, 12, 3269-3340, https://doi.org/10.5194/essd-12-3269-2020

[302] Friedlingstein, P. et al. (2021) Global Carbon Budget 2021, submitted to Earth Syst. Sci. Data, https://doi.org/10.5194/essd-2021-386

2028 through 2034, for example, the Project would be adding emissions at 20 – 30% of the rate that NSW was attempting to reduce them. Comparison of Figs. 36 and 37 graphically illustrates why **it is misleading to consider only the fraction of a Project's emissions to current State emissions, rather than to the climate emissions policy of the State, particularly one with relatively ambitious targets.**

309) I note that should any of the alternate scenarios considered in Section 5 and displayed in Table 3 eventuate, the negative impact of the Project on meeting GHG targets would be proportionally increased.

310) Moreover, some of the emissions that the Project has labelled as Scope 3 in its EIS, may be Scope 1 emissions for NSW and Australia, since some of its product coal may be used and combusted locally. Indeed, this possibility is listed as a justification for the Project in the EIS.[303] As Scope 3 emissions represent the lion's share of the Project's total direct and indirect GHG emissions, **if even 15% its product coal were used in NSW, the Project's impact on the state's direct emissions would more than double**.

311) In Table 8 below, **average annual Project GHG emissions (Scopes 1 and 2) in the years up to and including 2030 are compared to the size of annual emissions *reduction* that will be required annually from 2022 in order for the country and the State to achieve their respective 2030 GHG emission targets**. Values are expressed both in Mt CO_2-e, and as a percentage.

Table 8: Average effect of the Project on meeting 2030 emission reduction targets

	Annual Quantity	**Dendrobium SSI Extension Average Annual Contribution over this period**
AUS 2030 Target Annual *change* from 2022 required to meet 43% reduction on 2005 levels (624.2 MtCO_2-e) by 2030	– 14.25 Mt CO_2-e	0.595 CO_2-e or +4.2% in the wrong direction
NSW 2030 Target Annual *change* from 2022 required to meet 50% reduction on 2005 levels (165.0 MtCO_2-e) by 2030	– 4.71 Mt CO_2-e	0.595 Mt CO_2-e or + 12.6% in the wrong direction

[303] EIS, Section 8, Justification of the Project

312) The results of the analysis displayed in Table 8 above show that the **average annual** (Scope 1 + Scope 2) **emissions** from the **Project** through 2030 is 0.595 Mt CO2-e, which is 0.44% of NSW 2019 total emissions, and **equivalent to the total current emissions of over 35,000 individual NSW residents**, when considering the State's emissions on a per capita basis.

313) **Despite being operational for only a portion of this decade, the Project alone would make Australia's 2030 target 4.2% more difficult to meet**, since with it, Australia would need to find 14.845 Mt CO_2-e (instead of 14.25 MtCO_2-e) of new emission reductions each year through 2030.

314) Meeting the NSW's 2030 target will require an annual new *reduction* of about 4.71 MtCO_2-e per year, year on year, whereas the Project would *add* 0.595 Mt CO_2-e every year through 2030 on average**. Thus, if the Project were to proceed,** NSW would need to find a total of 5.305 Mt CO_2-e (rather than 4.71 MtCO_2-e) new emission reductions each year through 2030, and **the difficulty of meeting the State's 2030 target would be increased by nearly 13%.**

315) I note that an oft overlooked aspect of continued and increased coal mining is the emissions produced *after* the mine is closed or abandoned. Recent work[304] shows that methane emissions from the growing population of abandoned mines will increase faster than those from active ones. By considering the number, size and depth of coal mines, the type of coal, the rate of abandonment, and end-stage measures (such as whether mine is flooded), it has been estimated **that abandoned mine methane accounted for 17% of total global coal mining emissions in 2010**. These emissions will grow in time, and will do so faster if coal mining development increases rather than declines. **If the Project is approved, it will continue to emit additional methane long after the mine is closed.**

316) Finally, **when considering the effect of the Project on climate change, one must consider all its emissions, direct and indirect, which contribute to climate change and the environment of NSW equally on a tonne-per-tonne basis**. In order to visualise this

[304] Kholod, N. et al. (2020) Global methane emissions from coal mining to continue growing even with declining coal production. Journal of Cleaner Production, 256, 120489. Accessed at: https://www.sciencedirect.com/science/article/pii/S0959652620305369?via%3Dihub

effect, compared to the GHG reductions that NSW will be undertaking to meet its climate goals, I plot in Figure 38 the total of all Scopes (1, 2 and 3) from the Project over its lifetime, as given in the EIS GHG Estimates.

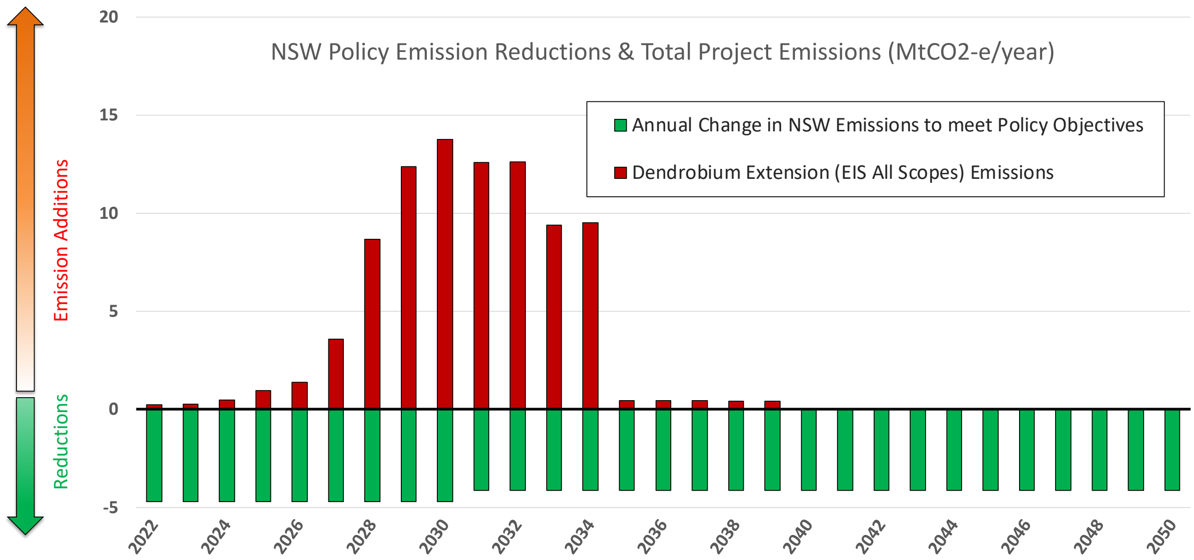

Fig. 38: Size of annual total emissions (Scopes 1, 2 and 3) from the Project (red) compared to the annual reductions necessary in a simple model in order for New South Wales to meet both its stated 2030 and 2050 targets in the linear fashion (green).

317) Figure 38 makes clear that **the Dendrobium SSI Extension Project, on its own, negates several times over the climate benefit of NSW meeting its 2030 GHG emissions target.**

8.4 Precautionary Principle and Intergenerational Equity

318) As this Report has set out, **the effects of climate change – which are caused by anthropogenic GHG emissions – are already serious; more than that, they are in fact dangerous. Furthermore, some of these effects are already irreversible and more will become so with even relatively small amounts of additional warming beyond that of 1.5°C, which is already locked in**.

319) Every tonne of GHG emission leads to (more) dangerous warming. It is not possible to know which amount, from which source, will precipitate environmental subsystems, including those in NSW, to tip irreversibly. In this context, the Precautionary Principle certainly applies.

320) Unabated climate change is likely to be greatest overall threat to the environment and people of New South Wales (NSW) because it is comprehensively dangerous, global,

fundamental, rapid, compounding, self-reinforcing, has delayed effects and, in some cases, is irreversible.

321) In my opinion, **environmentally sustainable development is development that avoids the catastrophic risks that climate change poses, noting the special nature of climate change as a risk not only to the natural environment, but also human health, well-being and livelihoods.**

322) **The argument** put by the Applicant **that Project emissions represent a very small fraction of NSW, national or global emissions is irrelevant and misleading. If individual consent authorities around the world were to accept this argument and act upon it to approve fossil fuel expansion projects, the climate change predicament would, *per force*, continue to worsen.**

323) **The climate change externalities of the Project will be borne disproportionately by younger and future generations, with no clear recourse or path to remediation.** Given that any future emissions 'lock in' extra warming, there is no possibility for true `remediation' of the climate damages caused by emissions from the Project. These damages include deterioration in the health, diversity and productivity of the environment, and have direct consequences for human health and livelihood. Currently, **the `polluter pays' principle is certainly not being applied to the damages associated with GHG emissions**.

324) In conclusion**, based on the evidence presented in this Report of the enormous risks posed by global warming surpassing 2°C, including irreversible consequences, and the contribution of the Dendrobium SSI Extension in increasing that likelihood, it is my view that any benefits of the Project are far outweighed by costs borne by the majority of NSW inhabitants, particularly the youngest.**

Respectfully submitted on 10 June 2022,

Penny D Sackett

Professor Penny D Sackett

Appendix A: Brief Provided to Author by the EDO

See attached pages.

Environmental Defenders Office

25 May 2022

Dr Penny D Sackett
Strategic Advisory Services

By email: pd.sackett@gmail.com

CONFIDENTIAL AND PRIVILEGED

Dear Professor Sackett,

Brief to Expert – Dendrobium Mine Extension Project SSI – 33143123

1. We act for Protect Our Water Catchment (**POWC**) in relation to the proposed Dendrobium Mine Extension Project (SSI - 33143123) (**Project**) by Illawarra Coal Holdings Pty Ltd (**Applicant**), a subsidiary of South32 Limited.

2. The Project is an extension of the Applicant's existing underground coal mine located around 8 km west of Wollongong in the Southern Coalfield of New South Wales (**NSW**). The Applicant is seeking development consent to extract up to 5.2 million tonnes per annum (Mtpa) of ROM coal, through underground mining operations within Area 5 (location of the Project) until approximately 2035, in extending the life of Dendrobium Mine until 2041. The Project is a redesign of the Applicant's previous Significant State Development (**SSD**) application (Dendrobium Extension Project, SSD 8194).

3. Our client intends to make a submission on the Project, which is currently being publicly exhibited, to ensure the decision-maker has independent expert advice on the Project.

4. We seek to engage you on behalf of our client to review the environmental impact statement (**EIS**) for the Project and prepare an independent expert report in relation to your area of expertise, greenhouse gases and climate change, in accordance with the *Uniform Civil Procedure Rules 2005* (UCPR) and the Expert Witness Code of Conduct.

Background

5. On 5 February 2021, the Applicant's SSD application (Dendrobium Extension Project, SSD 8194) for the Project was refused by the Independent Planning Commission (**IPC**). The

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ABN: 72002 880 864

Applicant appealed the IPC's decision, which is currently the subject of a judicial review proceedings in the Land and Environment Court of New South Wales.

6. On or around December 2021, the Applicant submitted a scoping report for the re-designed SSD Project in support of the application for the Project to be assessed as 'State significant infrastructure' (**SSI**).

7. On 2 December 2021, the Project was declared SSI by the Minister for Planning and Public Spaces.

8. On 23 December 2021, the Department of Planning, Industry and Environment (now the Department of Planning and Environment) issued the Planning Secretary's environmental assessment requirements (SEARs) for the Project.

9. On 4 May 2022, the Project application, EIS and accompanying documents were placed on public exhibition.

Purpose of your expert report

10. We note as a preliminary matter that our primary purpose in briefing you to prepare your report is to provide independent expert advice in your area of expertise. We do not ask you to be an advocate for our client/s. You are requested to prepare an independent report that is clear and well-written.

11. In this respect, we draw your attention to Part 31 Division 2 of the *Uniform Civil Procedure Rules 2005* (NSW) (**UCPR**) and the Expert Witness Code of Conduct (**Code of Conduct**) which govern the use of expert evidence in NSW Courts (**attached**). The SSI public exhibition process is not a Court proceeding; however, we are of the view that the same Code of Conduct should be adhered to in this instance.

12. In particular, clause 2 of the Code of Conduct states that:

> *"An expert witness is not an advocate for a party and has a paramount duty, overriding any duty to the party to the proceedings or other person retaining the expert witness, to assist the court impartially on matters relevant to the area of expertise of the witness."*

13. Your expert report must contain an acknowledgment that you have read the Expert Witness Code of Conduct and that you agree to be bound by it.

14. Your expert report will be used as evidence in chief of your professional opinion. Information of which you believe the decision maker should be aware must be contained in your expert report.

15. In providing your opinion to the decision maker you must set out all the assumptions upon which the opinion is based. This may include, for example, facts observed as a result of fieldwork or 'assumed' facts based on a body of scientific opinion. If the latter, you should provide references which demonstrate the existence of that body of opinion.

16. Your expert report must also set out the process of reasoning which you have undertaken in order to arrive at your conclusions. It is insufficient for an expert report to simply state your opinion or conclusion reached without an explanation as to how this was arrived at. The purpose of providing such assumptions and reasoning is to enable the decision maker and experts engaged by other parties to make an assessment as to the soundness of your opinion.

Overview of work requested

17. We request that you undertake the following work:
    a. review the documents listed below;
    b. prepare a written expert report that addresses the issues identified below ('Issues to address in your expert report'); and
    c. ensure that the work is prepared in accordance with independent expert advice as indicated above.

Documents

18. We enclose the Code of Conduct and Part 31 Division 2 of the UCPR.

19. Full Project documentation is available at the following website:
    a) NSW Government Planning Portal: https://www.planningportal.nsw.gov.au/major-projects/projects/dendrobium-mine-extension-project-0

20. The following documents relating to the Project are provided for your particular consideration:

    Environmental Impact Statement

    Executive Summary, https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSI-33143123%2120220427T061031.074%20GMT

    Section 1 – Introduction, https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSI-33143123%2120220427T061031.900%20GMT

    Section 7 – Environmental Assessment, https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSI-33143123%2120220427T061037.452%20GMT, pp. 7-150 to 7-155

    Section 8 – Justification of the Project, https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSI-33143123%2120220427T061039.685%20GMT

    Appendix I – Air Quality and GHG Assessment, https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSI-33143123%2120220427T061101.822%20GMT

    Appendix R – Greenhouse Gas Report, https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSI-33143123%2120220427T061053.099%20GMT

21. Other documents relating to the SSD application that may be of relevance include:

  a) IPC Dendrobium SSD Application Refusal - Statement of Reasons; and
  b) Independent Opinion of Professor Goodman on the Dendrobium Extension Project.

22. You are not limited to the above documents, if there is other material relevant to your expert report, you may wish to refer to this material.

Issues to address in your expert report

23. We ask that your report addresses the following issues in regard to any impacts arising as a result of the Project:

  a. In your opinion, how will the Project contribute to greenhouse gas emissions and climate change?
  b. In your opinion, what will be the impact of approval of this project on state and national targets for greenhouse gas emissions (CO_2 and methane) for 2030 and beyond, and in the context of the most recent Intergovernmental Panel on Climate Change (IPCC) recommendations?
  c. Under climate change for the region, temperatures and extreme fire weather will increase, rainfall and runoff are predicted to change. In your opinion, in considering climate change and any impacts to the Sydney drinking water catchment arising from the Project, do the claimed benefits of the Project outweigh its costs from a distributive equity perspective?
  d. Provide any further observations or opinions which you consider to be relevant.

24. We request that you provide us with a draft of your report for review before finalising it. We emphasise that the purpose of this is not to influence the conclusions or recommendations you make but to ensure that the language and expression of the report is clear and complies with the formal legal requirements of an expert report.

Key dates

25. The Project application, EIS and accompanying documents are on public exhibition from Wednesday 4 May 2022 until 14 June 2022.

26. We kindly request a draft of your expert advice by no later than **Wednesday 8 June 2022**.

27. Please provide your final expert advice by no later than **week ending 12 June 2022**.

Duty of confidentiality

28. Please treat your work as strictly confidential, unless authorised otherwise by us. Please mark all documents prepared for the purposes of this brief as "Privileged & Confidential".

Fees and Terms

29. Thank-you for agreeing to provide your advice in this matter on a pro bono (volunteer) basis. EDO relies on experts such as you to assist in matters with very little financial compensation.

30. Please note the following terms:

  a. your work will only be used by EDO to relation to this matter;
  b. either EDO or our client may choose to make your expert advice publicly available. Any public release of your report may result in disclosure of any works in your report over which you may claim copyright;
  c. EDO will take all reasonable steps to prevent your work being used for purposes other than that mentioned above, but we accept no responsibility for the actions of third parties;
  d. regardless of the above points, EDO may choose not to use your work; and
  e. you will not be covered by the EDO's insurance while undertaking the above tasks.

31. If you would like to discuss this brief further, please contact Jayme Cooper via email jayme.cooper@edo.org.au (cc: matthew.floro@edo.org.au and edward.butler@edo.org.au).

We are grateful for your assistance in this matter.

Yours sincerely,
Environmental Defenders Office

Jayme Cooper
Solicitor

Reference number: s 3326

NSW GOVERNMENT | NSW legislation

Uniform Civil Procedure Rules 2005

Current version for 1 December 2021 to date (accessed 25 May 2022 at 13:36)

Part 31 > Division 2

Division 2 Provisions applicable to expert evidence generally

Note—

The provisions of this Division replace those of former Divisions 2 and 3, as in force immediately before 8 December 2006. The numbering of the individual provisions of this Division varies considerably from that of the provisions of the former Divisions. The following Table identifies the new rules corresponding to former rules 31.17–31.35.

Table

Former rule	New rule
Rule 31.17	Rule 31.18
Rule 31.18	Rule 31.28
Rule 31.18A	Rule 31.29
Rule 31.19	Rule 31.30
Rule 31.20	Rule 31.31
Rule 31.21	Rule 31.32
Rule 31.22	Rule 31.33
Rule 31.23	Rule 31.27
Rule 31.24	Rule 31.34
Rule 31.25	Rules 31.24 and 31.26
Rule 31.26	Rule 31.35
Rule 31.27	Rule 31.36
Rule 31.28	Rule 31.18
Rule 31.29	Rule 31.46
Rule 31.30	Rule 31.23
Rule 31.31	Rule 31.49
Rule 31.32	Rule 31.51
Rule 31.33	Rule 31.52
Rule 31.34	Rule 31.53
Rule 31.35	Rule 31.54

Subdivision 1 Preliminary

31.17 Main purposes of Division (cf Queensland *Uniform Civil Procedure Rules 1999*, rule 423; United Kingdom *Civil Procedure Rules 1998*, rule 35.1)

The main purposes of this Division are as follows—

(a) to ensure that the court has control over the giving of expert evidence,

(b) to restrict expert evidence in proceedings to that which is reasonably required to resolve the proceedings,

(c) to avoid unnecessary costs associated with parties to proceedings retaining different experts,

(d) if it is practicable to do so without compromising the interests of justice, to enable expert evidence to be given on an issue in proceedings by a single expert engaged by the parties or appointed by the court,

(e) if it is necessary to do so to ensure a fair trial of proceedings, to allow for more than one expert (but no more than are necessary) to give evidence on an issue in the proceedings,

(f) to declare the duty of an expert witness in relation to the court and the parties to proceedings.

31.18 Definitions (cf SCR Part 36, rules 13A and 13C; DCR Part 28, rule 8; LCR Part 23, rule 1D)

In this Division—

court-appointed expert means an expert appointed pursuant to rule 31.46.

expert, in relation to any issue, means a person who has such knowledge or experience of, or in connection with, that issue, or issues of the character of that issue, that his or her opinion on that issue would be admissible in evidence.

expert witness means an expert engaged or appointed for the purpose of—

(a) providing an expert's report for use as evidence in proceedings or proposed proceedings, or

(b) giving opinion evidence in proceedings or proposed proceedings.

expert's report means a written statement by an expert (whether or not an expert witness in the proceedings concerned) that sets out the expert's opinion and the facts, and assumptions of fact, on which the opinion is based.

hospital report means a written statement concerning a patient, made by or on behalf of a hospital, that the party serving the statement intends to adduce in evidence in chief at the trial.

parties' single expert means an expert engaged pursuant to rule 31.37.

Subdivision 2 Expert witnesses generally

31.19 Parties to seek directions before calling expert witnesses

(1) Any party—

(a) intending to adduce expert evidence at trial, or

(b) to whom it becomes apparent that he or she, or any other party, may adduce expert evidence at trial,

must promptly seek directions from the court in that regard.

(2) Directions under this rule may be sought at any directions hearing or case management conference or, if no such hearing or conference has been fixed or is imminent, by notice of motion or pursuant to liberty to restore.

(3) Unless the court otherwise orders, expert evidence may not be adduced at trial—

(a) unless directions have been sought in accordance with this rule, and

(b) if any such directions have been given by the court, otherwise than in accordance with those directions.

(4) This rule does not apply to proceedings with respect to a professional negligence claim.

31.20 Court may give directions regarding expert witnesses

(1) Without limiting its other powers to give directions, the court may at any time give such directions as it considers appropriate in relation to the use of expert evidence in proceedings.

(2) Directions under this rule may include any of the following—

(a) a direction as to the time for service of experts' reports,

(b) a direction that expert evidence may not be adduced on a specified issue,

(c) a direction that expert evidence may not be adduced on a specified issue except by leave of the court,

(d) a direction that expert evidence may be adduced on specified issues only,

(e) a direction limiting the number of expert witnesses who may be called to give evidence on a specified issue,

(f) a direction providing for the engagement and instruction of a parties' single expert in relation to a specified issue,

(g) a direction providing for the appointment and instruction of a court-appointed expert in relation to a specified issue,

(h) a direction requiring experts in relation to the same issue to confer, either before or after preparing experts' reports in relation to a specified issue,

(i) any other direction that may assist an expert in the exercise of the expert's functions,

(j) a direction that an expert who has prepared more than one expert's report in relation to any proceedings is to prepare a single report that reflects his or her evidence in chief.

31.21 Expert evidence in chief to be given by way of experts' reports

Unless the court otherwise orders, an expert witness's evidence in chief must be given by the tender of one or more expert's reports.

31.22 Expert witness to provide details of contingency fees or deferred payment schemes

(1) A person who is engaged as an expert witness in relation to any proceedings must include information as to any arrangements under which—

(a) the charging of fees or costs by the expert witness is contingent on the outcome of the proceedings, or

(b) the payment of any fees or costs to the expert witness is to be deferred,

in, or in an annexure to, any report that he or she prepares for the purposes of the proceedings.

(2) If a report referred to in subrule (1) indicates the existence of any such arrangements, the court may direct disclosure of the terms of the engagement (including as to fees and costs).

31.23 Code of conduct (cf SCR Part 39, rule 2; DCR Part 28A, rule 2; LCR Part 38B, rule 2)

(1) An expert witness must comply with the code of conduct set out in Schedule 7.

(2) As soon as practicable after an expert witness is engaged or appointed—

(a) in the case of an expert witness engaged by one or more parties, the engaging parties, or one of them as they may agree, or

(b) in the case of an expert witness appointed by the court, such of the affected parties as the court may direct,

must provide the expert witness with a copy of the code of conduct.

(3) Unless the court otherwise orders, an expert's report may not be admitted in evidence unless the report contains an acknowledgment by the expert witness by whom it was prepared that he or she has read the code of conduct and agrees to be bound by it.

(4) Unless the court otherwise orders, oral evidence may not be received from an expert witness unless the court is satisfied that the expert witness has acknowledged, whether in an expert's report prepared in relation to the proceedings or otherwise in relation to the proceedings, that he or she has read the code of conduct and agrees to be bound by it.

31.24 Conference between expert witnesses (cf SCR Part 36, rule 13CA; DCR Part 28, rule 9D; LCR Part 23, rule 1E)

(1) The court may direct expert witnesses—

(a) to confer, either generally or in relation to specified matters, and

(b) to endeavour to reach agreement on any matters in issue, and

(c) to prepare a joint report, specifying matters agreed and matters not agreed and reasons for any disagreement, and

(d) to base any joint report on specified facts or assumptions of fact,

and may do so at any time, whether before or after the expert witnesses have furnished their experts' reports.

(2) The court may direct that a conference be held—

(a) with or without the attendance of the parties affected or their legal representatives, or

(b) with or without the attendance of the parties affected or their legal representatives, at the option of the parties, or

(c) with or without the attendance of a facilitator (that is, a person who is independent of the parties and who may or may not be an expert in relation to the matters in issue).

(3) An expert witness so directed may apply to the court for further directions to assist the expert witness in the performance of his or her functions in any respect.

(4) Any such application must be made by sending a written request for directions to the court, specifying the matter in relation to which directions are sought.

(5) An expert witness who makes such an application must send a copy of the request to the other expert witnesses and to the parties affected.

(6) Unless the parties affected agree, the content of the conference between the expert witnesses must not be referred to at any hearing.

31.25 Instructions to expert witnesses where conference ordered before report furnished

If a direction to confer is given under rule 31.24(1)(a) before the expert witnesses have furnished their reports, the court may give directions as to—

(a) the issues to be dealt with in a joint report by the expert witnesses, and

(b) the facts, and assumptions of fact, on which the report is to be based,

including a direction that the parties affected must endeavour to agree on the instructions to be provided to the expert witnesses.

31.26 Joint report arising from conference between expert witnesses (cf SCR Part 36, rule 13CA; DCR Part 28, rule 9D; LCR Part 23, rule 1E)

(1) This rule applies if expert witnesses prepare a joint report as referred to in rule 31.24(1)(c).

(2) The joint report must specify matters agreed and matters not agreed and the reasons for any disagreement.

(3) The joint report may be tendered at the trial as evidence of any matters agreed.

(4) In relation to any matters not agreed, the joint report may be used or tendered at the trial only in accordance with the rules of evidence and the practices of the court.

(5) Except by leave of the court, a party affected may not adduce evidence from any other expert witness on the issues dealt with in the joint report.

Subdivision 3 Experts' reports and expert evidence

31.27 Experts' reports (cf SCR Part 36, rule 13C; DCR Part 28, rule 9C; LCR Part 23, rule 1D)

(1) An expert's report must (in the body of the report or in an annexure to it) include the following—

(a) the expert's qualifications as an expert on the issue the subject of the report,

(b) the facts, and assumptions of fact, on which the opinions in the report are based (a letter of instructions may be annexed),

(c) the expert's reasons for each opinion expressed,

(d) if applicable, that a particular issue falls outside the expert's field of expertise,

(e) any literature or other materials utilised in support of the opinions,

(f) any examinations, tests or other investigations on which the expert has relied, including details of the qualifications of the person who carried them out,

(g) in the case of a report that is lengthy or complex, a brief summary of the report (to be located at the beginning of the report).

(2) If an expert witness who prepares an expert's report believes that it may be incomplete or inaccurate without some qualification, the qualification must be stated in the report.

(3) If an expert witness considers that his or her opinion is not a concluded opinion because of insufficient research or insufficient data or for any other reason, this must be stated when the opinion is expressed.

(4) If an expert witness changes his or her opinion on a material matter after providing an expert's report to the party engaging him or her (or that party's legal representative), the expert witness must forthwith provide the engaging party (or that party's legal representative) with a supplementary report to that effect containing such of the information referred to in subrule (1) as is appropriate.

31.28 Disclosure of experts' reports and hospital reports (cf SCR Part 36, rule 13A; DCR Part 28, rule 8; LCR Part 23, rule 3)

(1) Each party must serve experts' reports and hospital reports on each other active party—

(a) in accordance with any order of the court, or

(b) if no such order is in force, in accordance with any relevant practice note, or

(c) if no such order or practice note is in force, not later than 28 days before the date of the hearing at which the report is to be used.

(2) An application to the court for an order under subrule (1) (other than an order solely for abridgment or extension of time) may be made without serving notice of motion.

(3) Except by leave of the court, or by consent of the parties—

(a) an expert's report or hospital report is not admissible unless it has been served in accordance with this rule, and

(b) without limiting paragraph (a), an expert's report or hospital report, when tendered under section 63, 64 or 69 of the *Evidence Act 1995*, is not admissible unless it has been served in accordance with this rule, and

(c) the oral expert evidence in chief of any expert is not admissible unless an expert's report or hospital report served in accordance with this rule contains the substance of the matters sought to be adduced in evidence.

(4) Leave is not to be given as referred to in subrule (3) unless the court is satisfied—

(a) that there are exceptional circumstances that warrant the granting of leave, or

(b) that the report concerned merely updates an earlier version of a report that has been served in accordance with subrule (1).

31.29 Admissibility of expert's report (cf SCR Part 36, rule 13B)

(1) If an expert's report is served in accordance with rule 31.28 or in accordance with an order of the court, the report is admissible—

(a) as evidence of the expert's opinion, and

(b) if the expert's direct oral evidence of a fact on which the opinion was based would be admissible, as evidence of that fact,

without further evidence, oral or otherwise.

(2) Unless the court otherwise orders, a party may require the attendance for cross-examination of the expert by whom the report was prepared by notice served on the party by whom the report was served.

(3) Unless the court otherwise orders, such a requirement may not be made later than—

(a) in the case of proceedings for which the court has fixed a date for trial, 35 days before the date so fixed, or

(b) in any other case, 7 days before the date on which the court fixes a date for trial.

(4) The parties may not by consent abridge the time fixed by or under subrule (3).

(5) If the expert's attendance for cross-examination is required under subrule (2), the report may not be tendered under section 63, 64 or 69 of the *Evidence Act 1995* or otherwise used unless the expert attends or is dead or the court grants leave to use it.

(6) The party using the report may re-examine the expert if the expert attends for cross-examination pursuant to a requirement under subrule (2).

(7) This rule does not apply to proceedings in the District Court or the Local Court or to proceedings on a trial with a jury.

31.30 Admissibility of expert's report in District Court and Local Court (cf DCR Part 28, rule 9; LCR Part 23, rule 2)

(1) This rule applies to proceedings in the District Court or the Local Court.

(2) If an expert's report is served in accordance with rule 31.28 or in accordance with an order of the court, the report is admissible—

(a) as evidence of the expert's opinion, and

(b) if the expert's direct oral evidence of a fact on which the opinion was based would be admissible, as evidence of that fact,

without further evidence, oral or otherwise.

(3) Unless the court orders otherwise—

(a) it is the responsibility of the party requiring the attendance for cross-examination of the expert by whom an expert's report has been prepared to procure that attendance, and

(b) the party requiring the expert's attendance must notify the expert at least 28 days before the date on which attendance is required.

(4) Except for the purpose of determining any liability for conduct money or witness expenses, an expert does not become the witness for the party requiring his or her attendance merely because his or her attendance at court has been procured by that party.

(5) A party who requires the attendance of a person as referred to in subrule (2)—

(a) must inform all other parties to the proceedings that the party has done so at least 28 days before the date fixed for hearing, and

(b) must pay to the person whose attendance is required (whether before or after the attendance) an amount sufficient to meet the person's reasonable expenses (including any standby fees) in complying with the requirement.

(6) If the attendance of an expert is required under subrule (2), the report may not be tendered under section 63, 64 or 69 of the *Evidence Act 1995* or otherwise used unless the expert attends or is dead or the court grants leave to use it.

(7) The party using an expert's report may re-examine an expert who attends for cross-examination under a requirement under subrule (2).

(8) This rule does not apply to proceedings on a trial with a jury.

31.31 Fees for medical expert for compliance with subpoena (cf SCR Part 36, rule 13BA)

(1) If a subpoena is served on a medical expert who is to give evidence of medical matters but is not called as a witness, the expert is, unless the court orders otherwise, entitled to be paid, in addition to any other amount payable to the expert, the amount specified in item 2 of Schedule 3.

(2) The amount payable under subrule (1) must be paid to the expert by the issuing party within 28 days after the date for the expert's attendance.

(3) A party that requires an expert's attendance under rule 31.29(2), but subsequently revokes it, must pay to the issuing party any amount paid by the issuing party under subrule (2), but otherwise such an amount is not recoverable by the issuing party from any other party unless the court so orders.

(4) In this rule, ***issuing party*** means the party at whose request a subpoena is issued.

31.32 Service of subpoena on medical expert (cf SCR Part 36, rule 13BB)

(1) Service of a subpoena on a medical expert may be effected, at any place at which the expert's practice is carried on, by handing it over to a person who is apparently engaged in the practice (whether as an employee or otherwise) and is apparently of or above the age of 16 years.

(2) If a person refuses to accept a subpoena when it is handed over, the subpoena may be served by putting it down in the person's presence after he or she has been told of its nature.

(3) If a subpoena requires a medical expert to attend court on a specified date for the purpose of giving evidence on medical matters, it must be served on the expert not later than 21 days before the date so specified unless the court orders otherwise.

(4) The parties may not by consent abridge the time fixed by or under subrule (3).

31.33 Subpoena requiring production of medical records (cf SCR Part 36, rule 13BC)

(1) A subpoena for production may require a medical expert to produce medical records or copies of them.

(2) A person is not required to comply with a subpoena for production referred to in subrule (1) unless the amount specified in item 3 of Schedule 3 is paid or tendered to the person at the time of service of the subpoena or a reasonable time before the date on which production is required.

(3) Rule 33.6 (Compliance with subpoena) does not apply to a subpoena to which subrule (1) applies.

(4) Rule 33.7 (Production otherwise than on attendance) applies to the photocopies in the same way as it applies to the records.

(5) If, after service of a subpoena for production referred to in subrule (1), the party who requested the issue of the subpoena requires production of the original medical records without the option of producing copies of them, the party must request the issue of, and serve, another subpoena requiring production of the original medical records.

31.34 Supplementary reports by expert witness (cf SCR Part 36, rule 13C; DCR Part 28, rule 9C; LCR Part 23, rule 1D)

(1) If an expert witness provides a supplementary report to the party by whom he or she has been engaged, neither the engaging party nor any other party having the same interest as the engaging party may use—

(a) the supplementary report, or

(b) any earlier report affected by the supplementary report,

unless all of those reports have been served on all parties affected.

(2) For the purposes of this rule, ***supplementary report***, in relation to an earlier report provided by an expert witness, includes any report by the expert witness that indicates that he or she has changed his or her opinion on a material matter expressed in the earlier report.

(3) This rule does not apply to a report prepared by a court-appointed expert.

31.35 Opinion evidence by expert witnesses (cf *Federal Court Rules*, Order 34A, rule 3)

In any proceedings in which two or more parties call expert witnesses to give opinion evidence about the same issue or similar issues, or indicate to the court an intention to call expert witnesses for that purpose, the court may give any one or more of the following directions—

(a) a direction that, at trial—

(i) the expert witnesses give evidence after all factual evidence relevant to the issue or issues concerned, or such evidence as may be specified by the court, has been adduced, or

(ii) the expert witnesses give evidence at any stage of the trial, whether before or after the plaintiff has closed his or her case, or

(iii) each party intending to call one or more expert witnesses close that party's case in relation to the issue or issues concerned, subject only to adducing evidence of the expert witnesses later in the trial,

(b) a direction that, after all factual evidence relevant to the issue, or such evidence as may be specified by the court, has been adduced, each expert witness file an affidavit or statement indicating—

(i) whether the expert witness adheres to any opinion earlier given, or

(ii) whether, in the light of any such evidence, the expert witness wishes to modify any opinion earlier given,

(c) a direction that the expert witnesses—

(i) be sworn one immediately after another (so as to be capable of making statements, and being examined and cross-examined, in accordance with paragraphs (d), (e), (f), (g) and (h)), and

(ii) when giving evidence, occupy a position in the courtroom (not necessarily the witness box) that is appropriate to the giving of evidence,

(d) a direction that each expert witness give an oral exposition of his or her opinion, or opinions, on the issue or issues concerned,

(e) a direction that each expert witness give his or her opinion about the opinion or opinions given by another expert witness,

(f) a direction that each expert witness be cross-examined in a particular manner or sequence,

(g) a direction that cross-examination or re-examination of the expert witnesses giving evidence in the circumstances referred to in paragraph (c) be conducted—

(i) by completing the cross-examination or re-examination of one expert witness before starting the cross-examination or re-examination of another, or

(ii) by putting to each expert witness, in turn, each issue relevant to one matter or issue at a time, until the cross-examination or re-examination of all of the expert witnesses is complete,

(h) a direction that any expert witness giving evidence in the circumstances referred to in paragraph (c) be permitted to ask questions of any other expert witness together with whom he or she is giving evidence as so referred to,

(i) such other directions as to the giving of evidence in the circumstances referred to in paragraph (c) as the court thinks fit.

31.36 Service of experts' reports in professional negligence claims (cf SCR Part 14C, rules 1 and 6; DCR Part 28, rule 9B)

(1) Unless the court orders otherwise, a person commencing a professional negligence claim (other than a claim against a legal practitioner) must file and serve, with the statement of claim commencing the professional negligence claim, an expert's report that includes an opinion supporting—

(a) the breach of duty of care, or contractual obligation, alleged against each person sued for professional negligence, and

(b) the general nature and extent of damage alleged (including death, injury or other loss or harm and prognosis, as the case may require), and

(c) the causal relationship alleged between such breach of duty or obligation and the damage alleged.

(2) In the case of a professional negligence claim against a legal practitioner, the court may order the plaintiff to file and serve an expert's report or experts' reports supporting the claim.

(3) If a party fails to comply with subrule (1) or (2), the court may by order made on the application of a party or of its own motion dismiss the whole or any part of the proceedings, as may be appropriate.

(4) Without limiting subrule (1) or (2), the court may, on the application of any of the parties, give directions as to the expert evidence to be adduced at trial.

(5) Directions under subrule (4) may be sought at any directions hearing or case management conference or by notice of motion.

(6) Unless the court otherwise orders, no party may adduce any expert evidence at trial unless the evidence—

(a) has been filed and served under subrule (1) or (2), or

(b) has been served pursuant to directions given under subrule (4).

Subdivision 4 Parties' single experts

31.37 Selection and engagement

(1) If an issue for an expert arises in any proceedings, the court may, at any stage of the proceedings, order that an expert be engaged jointly by the parties affected.

(2) A parties' single expert is to be selected by agreement between the parties affected or, failing agreement, by, or in accordance with the directions of, the court.

(3) A person may not be engaged as a parties' single expert unless he or she consents to the engagement.

(4) If any party affected knows that a person is under consideration for engagement as a parties' single expert—

(a) the party affected must not, prior to the engagement, communicate with the person for the purpose of eliciting the person's opinion as to the issue or issues concerned, and

(b) if the party affected has previously communicated with the person for that purpose, he or she must notify the other parties affected as to the substance of those communications.

31.38 Instructions to parties' single expert

(1) The parties affected must endeavour to agree on written instructions to be provided to the parties' single expert concerning the issues arising for the expert's opinion and concerning the facts, and assumptions of fact, on which the report is to be based.

(2) If the parties affected cannot so agree, they must seek directions from the court.

31.39 Parties' single expert may apply to court for directions

(1) The parties' single expert may apply to the court for directions to assist the expert in the performance of the expert's functions in any respect.

(2) Any such application must be made by sending a written request for directions to the court, specifying the matter in relation to which directions are sought.

(3) A parties' single expert who makes such an application must send a copy of the request to the parties affected.

31.40 Parties' single expert's report to be sent to parties

(1) The parties' single expert must send a signed copy of his or her report to each of the parties affected.

(2) Each copy must be sent on the same day and must be endorsed with the date on which it is sent.

31.41 Parties may seek clarification of report

(1) Within 14 days after the parties' single expert's report is sent to the parties affected, and before the report is tendered in evidence, a party affected may, by notice in writing sent to the expert, seek clarification of any aspect of the report.

(2) Unless the court orders otherwise, a party affected may send no more than one such notice.

(3) Unless the court orders otherwise, the notice must be in the form of questions, no more than 10 in number.

(4) The party sending the notice must, on the same day as it is sent to the parties' single expert, send a copy of it to each of the other parties affected.

(5) Each notice sent under this rule must be endorsed with the date on which it is sent.

(6) Within 28 days after the notice is sent, the parties' single expert must send a signed copy of his or her response to the notice to each of the parties affected.

31.42 Tender of reports and of answers to questions

(1) Subject to rule 31.23(3) and unless the court orders otherwise, the parties' single expert's report may be tendered in evidence by any of the parties affected.

(2) Unless the court orders otherwise, any or all of the parties' single expert's answers in response to a request for clarification under rule 31.41 may be tendered in evidence by any of the parties affected.

31.43 Cross-examination of parties' single expert

Any party affected may cross-examine a parties' single expert, and the expert must attend court for examination or cross-examination if so requested on reasonable notice by a party affected.

31.44 Prohibition of other expert evidence

Except by leave of the court, a party to proceedings may not adduce evidence of any other expert on any issue arising in proceedings if a parties' single expert has been engaged under this Division in relation to that issue.

31.45 Remuneration of parties' single expert

(1) The remuneration of a parties' single expert is to be fixed by agreement between the parties affected and the expert or, failing agreement, by, or in accordance with the directions of, the court.

(2) Subject to subrule (3), the parties affected are jointly and severally liable to a parties' single expert for his or her remuneration.

(3) The court may direct when and by whom a parties' single expert is to be paid.

(4) Subrules (2) and (3) do not affect the powers of the court as to costs.

Subdivision 5 Court-appointed experts

31.46 Selection and appointment (cf SCR Part 39, rule 1; DCR Part 28A, rule 1; LCR Part 38B, rule 1)

(1) If an issue for an expert arises in any proceedings the court may, at any stage of the proceedings—

(a) appoint an expert to inquire into and report on the issue, and

(b) authorise the expert to inquire into and report on any facts relevant to the inquiry, and

(c) direct the expert to make a further or supplemental report or inquiry and report, and

(d) give such instructions (including instructions concerning any examination, inspection, experiment or test) as the court thinks fit relating to any inquiry or report of the expert or give directions concerning the giving of such instructions.

(2) The court may appoint as a court-appointed expert a person selected by the parties affected, a person selected by the court or a person selected in a manner directed by the court.

(3) A person must not be appointed as a court-appointed expert unless he or she consents to the appointment.

(4) If any party affected knows that a person is under consideration for appointment as a court-appointed expert—

(a) the party affected must not, prior to the appointment, communicate with the person for the purpose of eliciting the person's opinion as to the issue or issues concerned, and

(b) if the party affected has previously communicated with the person for that purpose, he or she must notify the court as to the substance of those communications.

31.47 Instructions to court-appointed expert

The court may give directions as to—

(a) the issues to be dealt with in a report by a court-appointed expert, and

(b) the facts, and assumptions of fact, on which the report is to be based,

including a direction that the parties affected must endeavour to agree on the instructions to be provided to the expert.

31.48 Court-appointed expert may apply to court for directions

(1) A court-appointed expert may apply to the court for directions to assist the expert in the performance of the expert's functions in any respect.

(2) Any such application must be made by sending a written request for directions to the court, specifying the matter in relation to which directions are sought.

(3) A court-appointed expert who makes such an application must send a copy of the request to the parties affected.

31.49 Court-appointed expert's report to be sent to registrar (cf SCR Part 39, rule 3; DCR Part 28A, rule 3; LCR Part 38B, rule 3)

(1) The court-appointed expert must send his or her report to the registrar, and a copy of the report to each party affected.

(2) Subject to rule 31.23(3) and unless the court orders otherwise, a report that has been received by the registrar is taken to be in evidence in any hearing concerning a matter to which it relates.

(3) A court-appointed expert who, after sending a report to the registrar, changes his or her opinion on a material matter must forthwith provide the registrar with a supplementary report to that effect.

31.50 Parties may seek clarification of court-appointed expert's report

Any party affected may apply to the court for leave to seek clarification of any aspect of the court-appointed expert's report.

31.51 Cross-examination of court-appointed expert (cf SCR Part 39, rule 4; DCR Part 28A, rule 4; LCR Part 38B, rule 4)

Any party affected may cross-examine a court-appointed expert, and the expert must attend court for examination or cross-examination if so requested on reasonable notice by a party affected.

31.52 Prohibition of other expert evidence (cf SCR Part 39, rule 6; DCR Part 28A, rule 6; LCR Part 38B, rule 6)

Except by leave of the court, a party to proceedings may not adduce evidence of any expert on any issue arising in proceedings if a court-appointed expert has been appointed under this Division in relation to that issue.

31.53 Remuneration of court-appointed expert (cf SCR Part 39, rule 5; DCR Part 28A, rule 5; LCR Part 38B, rule 5)

(1) The remuneration of a court-appointed expert is to be fixed by agreement between the parties affected and the expert or, failing agreement, by, or in accordance with the directions of, the court.

(2) Subject to subrule (3), the parties affected are jointly and severally liable to a court-appointed witness for his or her remuneration.

(3) The court may direct when and by whom a court-appointed expert is to be paid.

(4) Subrules (2) and (3) do not affect the powers of the court as to costs.

31.54 Assistance to court by other persons (cf SCR Part 39, rule 7; DCR Part 28A, rule 7; LCR Part 38B, rule 7)

(1) In any proceedings, the court may obtain the assistance of any person specially qualified to advise on any matter arising in the proceedings and may act on the adviser's opinion.

(2) Rule 31.53 applies to and in respect of a person referred to in subrule (1) in the same way as it applies to and in respect of a court-appointed witness.

(3) This rule does not apply to proceedings in the Admiralty List of the Supreme Court or to proceedings that are tried before a jury.

NSW GOVERNMENT | NSW legislation

Uniform Civil Procedure Rules 2005

Current version for 1 December 2021 to date (accessed 25 May 2022 at 13:36)

Schedule 7

Schedule 7 Expert witness code of conduct

(Rule 31.23)

1 Application of code

This code of conduct applies to any expert witness engaged or appointed—

(a) to provide an expert's report for use as evidence in proceedings or proposed proceedings, or

(b) to give opinion evidence in proceedings or proposed proceedings.

2 General duties to the Court

An expert witness is not an advocate for a party and has a paramount duty, overriding any duty to the party to the proceedings or other person retaining the expert witness, to assist the court impartially on matters relevant to the area of expertise of the witness.

3 Content of report

Every report prepared by an expert witness for use in court must clearly state the opinion or opinions of the expert and must state, specify or provide—

(a) the name and address of the expert, and

(b) an acknowledgement that the expert has read this code and agrees to be bound by it, and

(c) the qualifications of the expert to prepare the report, and

(d) the assumptions and material facts on which each opinion expressed in the report is based (a letter of instructions may be annexed), and

(e) the reasons for and any literature or other materials utilised in support of each such opinion, and

(f) (if applicable) that a particular question, issue or matter falls outside the expert's field of expertise, and

(g) any examinations, tests or other investigations on which the expert has relied, identifying the person who carried them out and that person's qualifications, and

(h) the extent to which any opinion which the expert has expressed involves the acceptance of another person's opinion, the identification of that other person and the opinion expressed by that other person, and

(i) a declaration that the expert has made all the inquiries which the expert believes are desirable and appropriate (save for any matters identified explicitly in the report), and that no matters of significance which the expert regards as relevant have, to the knowledge of the expert, been withheld from the court, and

(j) any qualification of an opinion expressed in the report without which the report is or may be incomplete or inaccurate, and

(k) whether any opinion expressed in the report is not a concluded opinion because of insufficient research or insufficient data or for any other reason, and

(l) where the report is lengthy or complex, a brief summary of the report at the beginning of the report.

4 Supplementary report following change of opinion

(1) Where an expert witness has provided to a party (or that party's legal representative) a report for use in court, and the expert thereafter changes his or her opinion on a material matter, the expert must forthwith provide to the party (or that party's legal representative) a supplementary report which must state, specify or provide the information referred to in clause 3(a), (d), (e), (g), (h), (i), (j), (k) and (l), and if applicable, clause 3(f).

(2) In any subsequent report (whether prepared in accordance with subclause (1) or not), the expert may refer to material contained in the earlier report without repeating it.

5 Duty to comply with the court's directions

If directed to do so by the court, an expert witness must—

(a) confer with any other expert witness, and

(b) provide the court with a joint report specifying (as the case requires) matters agreed and matters not agreed and the reasons for the experts not agreeing, and

(c) abide in a timely way by any direction of the court.

6 Conferences of experts

Each expert witness must—

(a) exercise his or her independent judgment in relation to every conference in which the expert participates pursuant to a direction of the court and in relation to each report thereafter provided, and must not act on any instruction or request to withhold or avoid agreement, and

(b) endeavour to reach agreement with the other expert witness (or witnesses) on any issue in dispute between them, or failing agreement, endeavour to identify and clarify the basis of disagreement on the issues which are in dispute.

Appendix B: Curriculum Vitae of Author

See attached pages.

Curriculum Vitae
PENNY D. SACKETT

Academic Address:	**Private Business Address:**
ANU Institute for Climate, Energy and Disaster Solutions	Dr Penny D Sackett
Australian National University	Strategic Advisory Services
H.C Coombs Building, 9 Fellows Road, Acton ACT 2601	
Penny.Sackett@anu.edu.au	www.pennysackett.com

Born: 28 February 1956, Lincoln, Nebraska USA
Citizenship: U.S. and Australian
Permanent Residence: Australia
Languages: English: Mother Tongue; Dutch: Good knowledge; Spanish: Beginner's knowledge

Education:

1984	Ph.D. in Physics, University of Pittsburgh, PA, USA Thesis Title: *Scale Parameters for Finite Temperature Actions of Lattice Gauge Theories Coupled to Fermions*
1980	M.S. in Physics, University of Pittsburgh, PA, USA
1978	B.S. in Physics, University of Nebraska-Omaha (UNO), NE, USA
1978	Teaching certification (K-12), Physics and Mathematics, UNO, USA

Distinctions and Honours:

2019	Distinguished Alumni Award, University of Pittsburgh, USA
2016	Omaha (USA) North High Magnet School "Viking of Distinction" Award
2014	UNO College of Arts and Sciences Outstanding Alumni Award
2014	Citation for Alumni Achievement: Univeristy of Nebraska-Omaha (UNO)
2011	Opening Keynote Speaker: 2011 Adelaide Festival of Ideas, SA, Australia
2005	Univ of Canberra-Australian National Univ International Women's Day Lecturer
2004	Finalist, Telstra ACT Business Women of the Year, ACT, Australia
2003	Fellow of the UK Royal Astronomical Society *Election to the Society to honour a person eminent in the field of astronomy and not normally resident in the UK for leadership, enabling activities, etc*
2002	Harley Wood Lecturer, Astronomical Society of Australia
2000	Athena Lecturer, St. Andrews University, Scotland
1998	University of Groningen Teaching Award (Onderwijsprijs), The Netherlands
1992-1994	J. Seward Johnson Fellow, Institute of Advanced Study, Princeton, NJ, USA
1981-1982	O.H. Blackwood Award for Excellence in Teaching, University of Pittsburgh, PA, USA
1979-1981	Andrew Mellon Fellowship, University of Pittsburgh, PA, USA
1978	Summa Cum Laude, University of Nebraska-Omaha, NE, USA
1978	Most Outstanding Physics Student, University of Nebraska-Omaha, NE, USA
1978	Most Outstanding Mathematics Student, University of Nebraska-Omaha, NE
1974-1978	Dean's List, University of Nebraska-Omaha, NE, USA
1974-1978	Nebraska Regent's Scholarship, University of Nebraska-Omaha, NE, USA
1974-1978	National Merit Scholarship, University of Nebraska-Omaha, NE, USA

Professional Society Membership

Astronomical Society of Australia
International Astronomical Union
Royal Astronomical Society

Professional Activity and Appointments

2020-current	Distinguished Honorary Professor (E3), Climate Change Institute, Australian National University, Canberra, Australia *Climate change synthesis and analysis, community engagement*
2011-current	Strategic Scientific Advisor and Principal Penny D Sackett Strategic Advisory Services *Sole trader assisting governments, communities, courts and business with matters of science, climate change and sustainability*
2014-2019	Honorary Professor, Climate Change Institute, Australian National University, Canberra, Australia *Community engagement, science for policy, subnational climate change action*
2008-2014	Academic Adjunct Professor, Research School of Astronomy and Astrophysics, Australian National University, Canberra, Australia *Mentoring early career researchers*
2008-2011	Chief Scientist for Australia, DIISR, Australian Commonwealth Government, Canberra, Australia *Provision of independent, whole-of-government scientific advice, science advocacy, liaison with community, bureaucracy and state governments*
2007-2008	Professor (Level E2), Research School of Astronomy and Astrophysics, Australian National University (ANU), Canberra, Australia *Research, research training, and international research co-ordination*
2002-2007	Director, Research School of Astronomy and Astrophysics, and the Mt. Stromlo and Siding Springs Observatories, ANU, Canberra, Australia *Strategic leadership, budget, human & facility management, liaison, advocacy*
2001-2002	Chaired Professor of (Extra)Galactic Optical/Infrared Astronomy, Kapteyn Astronomical Institute, University of Groningen, The Netherlands *Research, research training, teaching, international program building*
1998-2000	Associate Professor with tenure (Universiteits Hoofd Docent), Kapteyn Astronomical Institute, University of Groningen, The Netherlands *Research, research training, teaching, international program building*
2000	Visiting Member, Institute for Advanced Study, Princeton, NJ, USA (on leave from Kapteyn Institute 1999-2000 academic year) *Research of international standing*
1999	Visiting Scientist, Anglo-Australian Observatory, Epping, Australia (on leave from Kapteyn Institute 1999-2000 academic year) *Research of international standing and international co-ordination*
1995-1997	Assistant Professor with tenure (Universiteits Docent), 75% full time Kapteyn Astronomical Institute, University of Groningen, The Netherlands *Research, research training, teaching, research program building*
1995-1997	Visiting Research Member, School of Natural of Sciences, 25% full time Institute of Advanced Study, Princeton, NJ, USA *Research of international standing*
1992-1994	Research Member & J. Seward Johnson Fellow, School of Natural of Sciences, Institute of Advanced Study, Princeton, NJ, USA *Self-directed research of international standing*

1991-1992	Program Director, Education, Human Resources and Special Programs, Div of Astronomical Sciences, National Science Foundation, Washington, DC, USA *Program management, cross-division initiatives, external liaison*
1990-1992	Research Assistant Professor, Physics and Astronomy Department, University of Pittsburgh, PA, USA *Self-directed research*
1987-1990	Adjunct Assistant Professor, Physics and Astronomy Department, University of Pittsburgh, PA, USA *Self-supported research post*
1988-1989	Visiting Scientist, Kapteyn Astronomical Institute, University of Groningen, The Netherlands *Self-directed independent research*
1987	Scientific Writing Consultant, Pittsburgh Supercomputing Center (PSC), Pittsburgh, PA, USA *Technical writing and editing*
1986-1987	Research Associate, Biological Sciences Department, University of Pittsburgh, PA, USA *Algorithm development and application to cellular activity*
1985-1986	Visiting Assistant Professor, Physics and Astronomy Department, University of Pittsburgh, PA, USA *University physics teaching*
1983-1985	Visiting Assistant Professor, Physics Department, Amherst College, MA, USA *University teaching in liberal arts setting*
Summer 1983	Science Writer Intern, *Science News* Magazine, Washington, DC, USA *Developing and writing science news stories*

Supervision of Junior Researchers

Researcher name	Sackett Supervisory Capacity	Subsequent posting
Paul Vreeswijk	1997 Honours Thesis Supervisor	Fellow, Weizmann Inst of Science, IL
Jean Philippe Beaulieu	1996-98 Postdoctoral Supervisor	Director of Research, IAP, Paris, FR
Martin Dominik	1997-99 Postdoctoral Supervisor	Reader, Univ of St Andrews, UK
Richard Naber	PhD Thesis (Co-supervisor)	Left field before completion
Scott Gaudi	2001 PhD Thesis (Co-supervisor)	Professor, Ohio State University, USA
Eduard Westra	2003 Honours Thesis Supervisor	Industrial Data Analyist, NL
Ulyana Dyudina	2004 Postdoctoral Supervisor	Assoc Scientist, Space Science Inst, USA
Jelte de Jong	2005 PhD Thesis (Co-supervisor)	Researcher, University of Groningen, NL
David Weldrake	2005 PhD Thesis Supervisor	Asst Director, M-D Basin Authority, AU
Brandon Tingley	2006 PhD Thesis Supervisor	PostDoc, Aarhus University, DK
Christine Thurl	2007 PhD Thesis Supervisor	Industrial Physicist, DE
Thomas Evans	2008 Honours Supervisor	Research Fellow, Univ of Exeter, UK
Daniel Bayliss	2009 PhD Thesis Supervisor	Asst Professor, Univ of Warwick, UK
Karen Lewis	2011 PhD Thesis (Co-supervisor)	Postdoc, Earth Life Science Inst, JP

Selected Major Experiences and Accomplishments

2011-present *As Private Strategic Scientific Advisor:*

– Sole Expert Witness in BSCA vs EPA case in NSW Land and Environment Court
– Foresight analyst for 2025 Strategic Plan of BASF, world's largest chemical producer
– Scientific Assessor for Queensland $20m Smart Futures Fund
– Analyst and advisor to Australian multi-state Climate Action Roundtable

2015-2021 *As Councillor and Chair of ACT Climate Change Council:*

– Spearheaded recommendation for interim GHG emissions targets in the ACT
– With Prof. Will Steffen, introduced carbon budget approach into ACT policy-making
– Led *Canberra's Climate-Fuelled Summer of Crisis* Report

2008-2011 *As Chief Scientist for Australia:*

– Commissioned four cross-disciplinary reports for Prime Minister's Council (PMSEIC):
Challenges at energy-water-carbon intersections
Australia and food security in a changing world
Transforming learning and the transmission of knowledge
Epidemics in a changing world
– Founded Forum of Australian Chief Scientists
– Established two-way communication tools with Australian community

2002-2007 *As Director, Research School of Astronomy and Astrophysics (RSAA)*

– Managed University department and observatory staff of 100
– Responsible for annual budget of 6M AUD plus 4M AUD in 2nd & 3rd steam funds
– Oversaw rebuild of main campus of School after devastating 2003 bush fires
– Led national effort to establish next generation telescope access for Australia
– Established ANU Planetary Science Institute, joint venture with ANU Earth Sciences
– Initiated and carried out large change process at RSAA, managing
mandated 29% increase in salary costs & 20% reduction in recurrent budget
– Spearheaded entry into two major international partnerships:
Giant Magellan Telescope (GMT) and Murchison Wide Field Array (MWA)
– Negotiated awards of two major instrument contracts: Gemini NIFS (II) and GSAOI
– Oversaw 80% increase in research publication rate, 50% growth in PhD student body,
and increase in student completion rate while decrease in time to submission

1989-2010 *As Scientific Researcher and Team Leader in USA, NL and Australia:*

– Streamlined massive searches for transiting planets in the Milky Way
– Founded and Principal Investigator of the international PLANET Collaboration,
managing collaboration of 20 scientists in 7 countries using 5 telescopes to
set first limits for Jupiter-like planets around common dwarf stars,
determine limb-darkening of distant stars for the very first time, and
detect first terrestrial-mass (5-Earth mass) exoplanet around a normal star
– Determined 3-D distribution of dark matter around some galaxies
– Quantified relationship between structure and dark matter in Milky Way
– Determined deep cloud structure in atmosphere of Saturn

1991-1992 *As Program Director at U.S. National Science Foundation (NSF), USA*

– Managed program of small grants to fund high-risk science
– Initiated first newsletter from NSF Astronomy division (AST) to national community
– Managed all cross-division (AST + another NSF division) awards
– Responsible for all AST projects related to education and diversity
– Initiated study into factors correlated to proposal success and failure

Local, National & International Service

2015-2021	Councillor and Chair, Australian Capital Territory (ACT) Climate Change Council
2017-2020	Member, Business Advisory Board, ACT Renewable Energy Innovation Fund
2017-2019	Member, Scientific Advisory Board, Potsdam Institute for Climate Impact Research
2015	Chair, Memorandum Team, Nobel Laureate Symposium: *Climate Change, Changing Cities*
2013	Invited Speaker, 2013 Geological Society of America, Denver, CO, USA Contribution: *Elemental Cycles in the Anthropocene*
2011	Drafting Team, Nobel Laureate Stockholm Memorandum on Global Sustainability
2008-2011	As Chief Scientist for Australia, Member of: Prime Minister's Science, Engineering & Innovation Council, Executive Officer Prime Minister's Science Prize Selection Committee Educational Investment Fund Board Defence Science & Technology Organisation Advisory Board Rural Research & Development Council Higher Education Endowment Fund Assessment Panel Cooperative Research Centres Assessment Panel Climate Change Science Framework Implementation Group, Chair National Youth Science Forum, President Forum of Australian Chief Scientists, Founder and Chair
2005-2010	Board of Directors, Association of Universities for Research in Astronomy (AURA)
2006-2008	Board of Directors, Giant Magellan Telescope (GMT) Organisation
2002-2008	ANU Member Representative to AURA
2008	Australian GMT Advisory Committee to Australia Astronomy, Ltd
2003-2007	NCA Task Force on Extremely Large Telescopes (ELT)
2002-2007	National Committee for Astronomy (NCA), Australian Academy of Science
2002-2007	Australian Gemini Telescope Steering Committee
2002-2007	Board of Management for the Australian Astronomy MNRF Award
2004-2007	Chancellor's Award Committee, Australian National University (ANU)
2004-2006	Canberra Partnership Board, ACT, AU
2003-2005	University Science, Health & Engineering Research Committee, ANU
2000-2005	European OPTICON Extremely Large Telescope (ELT) Science Working Group
2004	International review team of the South African Astro-Geoscience Facilities for the NRF
2002-2003	Academic Board, Australian National University, Canberra, AU
1995-2002	Principal Investigator, International PLANET Collaboration
2001-2002	Science Advisory Committee for the Square Kilometer Array
2001-2002	Curriculum Advisory Committee for Astronomy, Kapteyn Astronomical Institute
2000-2002	European Southern Observatory (ESO) Programmes Committee, Member-at-Large
2000-2001	Chair, Stars and Planets Panel for OPTICON ELT Working Group
1996-1998	ESO Working Group on Exo-Solar Planets
1996-1998	Facilities Program Committee, Netherlands Organisation for Scientific Research

Scientific Organising and Steering Committees:

2013-2015	*Changing Climate, Changing Cities* Nobel Laureates Symposium on Global Sustainability, Hong Kong 2015 also Chair, Symposium Memorandum Drafting Team
2008	*2008 Meeting of the Astronomical Society of Australia* Perth, Australia
2006-2007	*IAU Symposium on Exoplanets: Physics, Dynamics and Evolution* Suzhou, China
2006	*Transiting Extrasolar Planets* 25-28 September 2006, MPIA, Heidelberg, Germany
2003-2004	*Planetary Timescales: Stardust to Continents* 2003 White Conference, National Academy of Sciences, Canberra, AU
2002-2003	*Extrasolar Planets: Today and Tomorrow* 30 June - 4 July 2003, IAP, Paris, France
2001-2002	*Scientific Frontiers in Research on Extrasolar Planets* 11-14 June 2002, Washington, DC, USA
2001	*The SKA: Defining the Future* 9-12 July 2001, Berkeley, CA, USA
2000-2001	*Yale Cosmology Workshop: Shapes of Galaxies and Their Halos* 28-30 May 2001, New Haven, USA
1999-2000	*Planetary Systems in the Universe: Observation, Formation and Evolution* 7-11 August 2000, Manchester, England
1998-2000	*Microlensing 2000: A New Era for Microlensing Astrophysics* 21-25 February 2000, Capetown, South Africa Chair, Scientific Organising Committee
1997-1999	*Impact of Large-Scale Photometry on the Research of Pulsating Stars* IAU Conference, 9-13 August 1999, Budapest, Hungary
1997-1999	*VLT Opening Symposium: From Extrasolar Planets to Brown Dwarfs* 1-4 March 1999, Antofagasta, Chile
1997-1998	*4^{th} International Workshop on Microlensing Surveys* 15-17 January 1998, Paris, France
1990	*Warped Disks and Inclined Rings around Galaxies* Workshop 30 May - 1 June 1990, Pittsburgh PA Scientific and Local Organising Committee

PUBLICATIONS

Over 140 publications, 65 in refereed journals, together garnering
more than 4400 scientific citations and 1000 normalised citations
(Sackett served as PhD or postdoctoral supervisor for authors in italics)

Technical Reports and Communications: Climate Change

Expert Report: On the Environmental Impact Statement of the Winchester South Project as it relates to Climate Change
Penny D Sackett
2021, Part of a submission to the Queensland Coordinator-General

Expert Report: Matter of Bushfire Survivors for Climate Action Inc v Environment Protection Authority
Affirmed as Affidavit D on 10 August 2021
Penny D Sackett
2021, Submission to the NSW Land and Environment Court, Case No. 20/106678

Expert Report: Matter of Bushfire Survivors for Climate Action Inc v Environment Protection Authority
Affirmed as Affidavit C on 5 August 2021
Penny D Sackett
2021, Submission to the NSW Land and Environment Court, Case No. 20/106678

Expert Report: Matter of Bushfire Survivors for Climate Action Inc v Environment Protection Authority
Affirmed as Affidavit B on 4 June 2021
Penny D Sackett
2021, Submission to the NSW Land and Environment Court, Case No. 20/106678

Expert Report: Matter of Bushfire Survivors for Climate Action Inc v Environment Protection Authority
Affirmed as Affidavit A on 5 March 2021
Penny D Sackett
2021, Submission to the NSW Land and Environment Court, Case No. 20/106678

The Social Cost of Carbon and Implications for the ACT
Paul Bannister, Cristopher Brack, Mark Howden, Karen Jesson, Ben Ponton, Penny D Sackett (Chair), Sophia Hamblin Wang
2021, ACT Climate Change Council, Canberra

Expert Submission: Tahmoor South Coal Extension Project (SSD 17-8845)
Objecting: On the basis of greenhouse gas implications
Addendum: Addendum in Response to Additional Material
Penny D Sackett
2020, Submission to the NSW Independent Planning Commission

Expert Report: Matter of Mullaley Gas & Pipeline Accord Inc v Santos NSW Pty Ltd; Independent Planning Commission of NSW
Affirmed as Affidavit C on 5 August 2021
Penny D Sackett
2021, Submission to the NSW Land and Environment Court, Case No. 20/363113

Expert Report: Greenhouse Gas and Climate Implications of the Narrabri Gas Project (SSD 6456)
Response to Additional Material
Penny D Sackett
2020, Submission to the NSW Independent Planning Commission

Expert Report: Greenhouse Gas and Climate Implications of the Narrabri Gas Project (SSD 6456)
Penny D Sackett
2020, Submission to the NSW Independent Planning Commission

Learning from Canberra's Climate-Fuelled Summer of Crisis
Paul Bannister, Cristopher Brack, Mark Howden, Karen Jesson, Ben Ponton, Penny D Sackett (Chair), Sophia Hamblin Wang
2020, ACT Climate Change Council, Canberra

Community Listening Report on Adaptation to Climate Crises: The Extreme Summer of 2019/20
Penny Sackett, Will Steffen and Karen Jessen
2020, ACT Climate Change Council, Canberra

Expert Submission: Tahmoor South Coal Extension Project (SSD 17-8845)
Objecting: On the basis of greenhouse gas implications
Addendum: In Response to the Greenhouse Gas Assessment of the Amended Project
Penny D Sackett
2020, Submission to the NSW Independent Planning Commission

Climate of fear: summit aims to create action consensus
S. Robson and P. Sackett
2020, in "Insight" of the Medical Journal of Australia, 2 March 2020

Expert Submission: Tahmoor South Coal Extension Project (SSD 17-8845)
Objecting: On the basis of greenhouse gas implications
Penny D Sackett
2019, Submission to the NSW Independent Planning Commission

Independent Assessment: Rix's Creek South Continuation of Mining Project (SSD 6300)
Objecting: On the basis of greenhouse gas implications
Penny D Sackett
2019, Submission to the NSW Independent Planning Commission

Who is Counting our Carbon Budget?
P.D. Sackett and W. Steffen
2019, in "Policy Forum" of the Asia and The Pacific Policy Society, 7 May 2019

What is a Carbon Budget?
Penny Sackett, Will Steffen and Karen Jessen
2018, ACT Climate Change Council, Canberra

Sub-National Climate Policies: How does the ACT compare? Part I: Report
Luke Kemp, Penny Sackett, and Frank Jotzo
2015, ACT Climate Change Council, Canberra

Sub-National Climate Policies: How does the ACT compare? Part II: Data Tables
Luke Kemp, Penny Sackett, and Frank Jotzo
2015, ACT Climate Change Council, Canberra

Refereed Scientific Publications

Elemental cycles in the Anthropocene: mining aboveground
Penny D. Sackett
2016, in Geoscience for the Public Good and Global Development: Toward a Sustainable Future, eds. G.R. Wessel and J.K. Greenberg, J.K., Geological Society of America Special Papers 520, p. SPE520-11, doi:10.1130/2016.2520(11)

HATS-3b: An Inflated Hot Jupiter Transiting an F-type Star
Daniel D. R. Bayliss et al (29 authors, including Penny D Sackett)
2013, AJ, 146, 113, arXiv:1306.0624

Endangered Elements: Conserving the Building Blocks of Life
(Invited Review) Penny Sackett
2012, Solutions, Volume 3, Issue 3

HATSouth: a global network of fully automated identical wide-field telescopes
G. Á. Bakos et al (24 authors, including *Daniel D. R. Bayliss* and Penny D. Sackett
2013, PASP, 125, 154, arXiv:1206.1391

The Frequency of Hot Jupiters in the Galaxy: Results from the SuperLupus Survey
Daniel D. R. Bayliss and Penny D. Sackett
2011, ApJ, 743, 103, arXiv:1112.0359

Confirmation of a Retrograde Orbit for Exoplanet WASP-17b
Daniel D. R. Bayliss, Joshua N. Winn, Rosemary A. Mardling & Penny D. Sackett
2010, ApJ Letters, 722, L224-L227, arXiv:1009.5061

An *a priori* Investigation of Astrophysical False Positives in Ground-Based Transiting Planet Surveys
Tom M. Evans & Penny D Sackett
2010, ApJ, 712, 38, arXiv:1002.0886

Microlensing exoplanets
Penny D Sackett
2010, Scholarpedia, 5(1):3991

The Lupus Transit Survey for Hot Jupiters: Results and Lessons
Daniel D. R. Bayliss, *David T. F. Weldrake*, Penny D. Sackett, *Brandon W. Tingley* & *Karen M. Lewis*
2009, AJ, 137, 4368, astro-ph/0903.5121

Possibility of Detecting Pulsar Moons through Time-of-Arrival Analysis
Karen M. Lewis, Penny D. Sackett & Rosemary A. Mardling
2008, ApJL, 685, L153, astro-ph/0805.4263

Lupus-TR-3b: A Low-Mass Transiting Hot Jupiter in the Galactic Plane?
David T. F. Weldrake, *Daniel D. R. Bayliss*, Penny D. Sackett, *Brandon W. Tingley*, Michaël Gillon & Johny Setiawan
2008, ApJL, 675, L37, astro-ph/0711.1746

The Frequency of Large Radius Hot and Very Hot Jupiters in ω Centauri
David T. F. Weldrake, Penny D. Sackett & Terry J. Bridges
2008, ApJ, 674, 1117, astro-ph/0710.3461

A Deep Wide-Field Variable Star Catalog of ω Centauri
David T. F. Weldrake, Penny D. Sackett & Terry J. Bridges
2007, AJ, 133, 1447, astro-ph/0610704

Resolving Stellar Atmospheres I: The Hα line and comparisons to microlensing observations
Christine Thurl, Penny D. Sackett & Peter H. Hauschildt
2006, A & A, 455, 315, astro-ph/0604088

MACHOs in M31? Absence of evidence but not evidence of absence
Jelte T.A. de Jong, Lawrence M. Widrow, Patrick Cseresnjes, Konrad Kuijken, Arlin P.S. Crotts, Alexander Bergier, Edward A. Baltz, Geza Gyuk, Penny D. Sackett, Robert R. Uglesich & Will J. Sutherland
2006, A & A, 446, 855, astro-ph/0507286

Discovery of a cool planet of 5.5 Earth masses through gravitational microlensing
J.-P. Beaulieu, et al (PLANET, OGLE and MOA, 73 authors, includ. Penny D. Sackett)
2006, Nature, 439, 437, astro-ph/0601563

The color signature of the transit of HD 209458 and discrepancies between stellar atmospheric models and observations
B. Tingley, *C. Thurl* & P. Sackett
2006, A & A, 445, L27, astro-ph/0510633

A Photometric Diagnostic to Aid in the Identification of Transiting Extra-solar Planets
Brandon Tingley & Penny D. Sackett
2005, ApJ, 627, 1011, astro-ph/0503575

An Absence of Hot Jupiter Planets in 47 Tucanae: Results of a Wide-Field Transit Search
David T.F. Weldrake, Penny D. Sackett, Terry J. Bridges, & Kenneth C. Freeman
2005, ApJ, 620, 1043, astro-ph/0411233

A Method for the Detection of Planetary Transits in Large Time-Series Datasets
David T.F. Weldrake & Penny D. Sackett
2005, ApJ, 620, 1033, astro-ph/0411234

Phase light curves for extrasolar Jupiters and Saturns
Ulyana A. Dyudina, Penny D. Sackett, *Daniel D.R. Bayliss*, Sara Seager, Carolyn C. Porco, Henry B. Throop & Luke Dones
2005, ApJ, 618, 973-986, astro-ph/0406390

A Comprehensive Catalogue of Variable Stars in the field of 47 Tucanae
David T.F. Weldrake, Penny D. Sackett, Terry J. Bridges, & Kenneth C. Freeman
2004, AJ, 128, 736, astro-ph/0405133

First Microlensing Results for the MEGA Survey of M31
Jelte T.A. de Jong, Konrad H. Kuijken, Arlin P.S. Crotts, Penny D. Sackett, Will J. Sutherland, Robert R. Uglesich, Edward A. Baltz, Patrick Cseresnjes, Geza Guyk, Lawrence M. Widrow (MEGA Collaboration)
2004, A & A, 417, 461-477, astro-ph/0307072

PLANET II: A Microlensing and Transit Search for Extrasolar Planets
Penny D. Sackett, M.D. Albrow, *J.-P. Beaulieu*, J.A.R. Caldwell, C. Coutures, *M. Dominik*, J. Greenhill, K. Hill, K. Horne, U.-G. Jorgensen, S. Kane, D. Kubas, R. Martin, J. Menzies, K.R. Pollard, K.C. Sahu, J. Wambsganss, R. Watson, A. Williams (PLANET),
in Bioastronomy 2002: Life Among the Stars, eds. R. Norris, C. Oliver & F. Stootman
2004, IAU Symposium 213 (San Francisco: ASP), 35, astro-ph/0211098

High-Precision Limb-Darkening Measurement of a K3 Giant Using Microlensing
D.L. Fields, M.D. Albrow, J.H. An, *J.-P. Beaulieu*, J.A.R. Caldwell, D.L. DePoy, *M. Dominik*, *B.S. Gaudi*, A. Gould, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, R.W. Pogge, K.R. Pollard, P.D. Sackett, K.C. Sahu, P. Vermaak, R. Watson & A. Williams (PLANET), and J.-F. Glicenstein & P.H. Hauschildt
2003, ApJ, 596, 1305, astro-ph/0303638

A Short, Non-Planetary Microlensing Anomaly: Observations and Lightcurve Analysis of MACHO 99-BLG-47
M.D. Albrow, J. An, *J.-P. Beaulieu*, J.A.R. Caldwell, D.L. DePoy, *M. Dominik*, *B.S. Gaudi*, A. Gould, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, R.W. Pogge, K.R. Pollard, P.D. Sackett, K.C. Sahu, P. Vermaak, R. Watson, A. Williams (PLANET)
2002, ApJ, 572, 1031, astro-ph/0201256

First microlens mass measurement: PLANET photometry of EROS BLG-2000-5
J. An, M.D. Albrow, *J.-P. Beaulieu*, J.A.R. Caldwell, D.L. DePoy, *M. Dominik*, *B.S. Gaudi*, A. Gould, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, R.W. Pogge, K.R. Pollard, P.D. Sackett, K.C. Sahu, P. Vermaak, R. Watson, A. Williams (PLANET)
2002, ApJ, 572, 521, astro-ph/0110095

Detection of a Thick Disk in the Edge-on Low Surface Brightness Galaxy ESO 342-G017
Mark J. Neeser, Penny D. Sackett, Guido De Marchi, & Francesco Paresce
2002, A&A, 383, 472, astro-ph/0201141

Microlensing Constraints on the Frequency of Jupiter-Mass Companions: Analysis of Five Years of PLANET Photometry
B.S. Gaudi, M.D. Albrow, J. An, *J.-P. Beaulieu*, J.A.R. Caldwell, D.L. DePoy, *M. Dominik*, A. Gould, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, *R.M. Naber*, J.-W. Pel, R.W. Pogge, K.R. Pollard, P.D. Sackett, K.C. Sahu, P. Vermaak, *P.M. Vreeswijk*, R. Watson, A. Williams (PLANET)
2002, ApJ, 566, 463, astro-ph/0104100

The PLANET microlensing follow-up network: Results and prospects for the detection of extra-solar planets
M. Dominik, M. D. Albrow, *J.-P. Beaulieu*, J. A. R. Caldwell, D. L. DePoy, *B. S. Gaudi*, A. Gould, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, *R. M. Naber*, J.-W. Pel, R. W. Pogge, K. R. Pollard, P.D. Sackett, K. C. Sahu, P. Vermaak, R. Watson, A. Williams (PLANET collaboration)
2002, Planetary and Space Science, 50, 299-307, astro-ph/9910465

Interpreting Debris from Satellite Disruption in External Galaxies
Kathryn V. Johnston, Penny D. Sackett and James S. Bullock
2001, ApJ, 557, 137, astro-ph/0101543

Hα Equivalent Width Variations across the Face of Microlensed K Giant in the Galactic Bulge
M.D. Albrow, J. An, *J.-P. Beaulieu*, J.A.R. Caldwell, *M. Dominik*, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, K.R. Pollard, P.D. Sackett, K.C. Sahu, P. Vermaak, R. Watson, A. Williams (PLANET), and P. Hauschildt
2001, ApJL, 550, L173, astro-ph/0011380

Limits on the Abundance of Galactic Planets from Five Years of PLANET Observations
M.D. Albrow, J. An, *J.-P. Beaulieu*, J.A.R. Caldwell, D.L. DePoy, M. Dominik, *B.S. Gaudi*, A. Gould, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, *R.M. Naber*, J.-W. Pel, R.W. Pogge, K.R. Pollard, P.D. Sackett, K.C. Sahu, P. Vermaak, *P.M. Vreeswijk*, R. Watson, A. Williams (PLANET)
2001, ApJL, 556, L113, astro-ph/0008078

PLANET observations of microlensing event OGLE-1999-BUL-23: Limb-darkening measurement of the source star
M.D. Albrow, J. An, *J.-P. Beaulieu*, J.A.R. Caldwell, D.L. DePoy, M. Dominik, *B.S. Gaudi*, A. Gould, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, R.W. Pogge, K.R. Pollard, P.D. Sackett, K.C. Sahu, P. Vermaak, R. Watson, A. Williams (PLANET Collaboration)
2001, ApJ, 549, 759, astro-ph/0004243

Discovery of the optical counterpart and early optical observations of GRB990712
K.C. Sahu et al. (49 authors, including P. D. Sackett and the PLANET collaboration
2000, ApJ, 540, 74, astro-ph/0003378

Limits on Stellar and Planetary Companions in Microlensing Event OGLE-1998-BUL-14
M.D. Albrow, *J.-P. Beaulieu*, J.A.R. Caldwell, D.L. DePoy, *M. Dominik*, *B.S. Gaudi*, A. Gould, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, *R.M. Naber*, R.W. Pogge, K.R. Pollard, P.D. Sackett, K.C. Sahu, P. Vermaak, R. Watson, A. Williams (PLANET)
2000, ApJ, 535, 176, astro-ph/9909325

Detection of Rotation in a Binary Microlens: PLANET Photometry of MACHO 97-BLG-41
M.D. Albrow, *J.-P. Beaulieu*, J.A.R. Caldwell, *M. Dominik*, *B.S. Gaudi*, A. Gould, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, *R.M. Naber*, K.R. Pollard, P.D. Sackett, K.C. Sahu, P. Vermaak, R. Watson, A. Williams (PLANET), H.E. Bond, I.M. van Bemmel
2000, ApJ, 534, 894, astro-ph/9910307

The Stellar Content of the Halo of NGC 5907 from Deep HST NICMOS Imaging
S.E. Zepf, M.C. Liu, F.R. Marleau, P.D. Sackett, & J.R. Graham
2000, AJ, 119, 1701, astro-ph/0001154

Combined Analysis of the Binary-Lens Caustic-Crossing Event MACHO 98-SMC-1
C. Afonso et. al., C. Alcock et al., S.H. Rhie et al., A. Udalski et al., M.D. Albrow et al. (94 authors in total, including P.D. Sackett: EROS, MACHO/GMAN, MPS, OGLE and PLANET Collaborations)
2000, ApJ, 532, 340, astro-ph/9907247

Detection Efficiencies of Microlensing Datasets to Stellar and Planetary Companions
B.S. Gaudi and P.D. Sackett
2000, ApJ, 528, 56, astro-ph/9904339

A Complete Set of Solutions For Caustic-Crossing Binary Microlensing Events
M.D. Albrow, *J.-P. Beaulieu*, J.A.R. Caldwell, D.L. DePoy, *M. Dominik*, *B.S. Gaudi*, A. Gould, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, *R.M. Naber*, R.W. Pogge, K.R. Pollard, P.D. Sackett, K.C. Sahu, P. Vermaak, R. Watson, A. Williams (PLANET Collaboration)
1999, ApJ, 522, 1022, astro-ph/9903008

Limb-Darkening of a K Giant in the Galactic Bulge: PLANET Photometry of MACHO 97-BLG-28
M.D. Albrow, *J.-P. Beaulieu*, J.A.R. Caldwell, *M. Dominik*, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, *R.M. Naber*, J.-W. Pel, K.R. Pollard, P.D. Sackett, K.C. Sahu, P. Vermaak, R. Watson, A. Williams (PLANET Collaboration) and M.S. Sahu
1999, ApJ, 522, 1011, astro-ph/9811479

The Relative Lens-Source Proper Motion in MACHO 98-SMC-1
M.D. Albrow, *J.-P. Beaulieu*, J.A.R. Caldwell, D.L. DePoy, *M. Dominik*, *B.S. Gaudi*, A. Gould, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, *R.M. Naber*, J.-W. Pel, K.R. Pollard, P.D. Sackett, K.C. Sahu, P. Vermaak, R. Watson, A. Williams (PLANET Collaboration), and R. W. Pogge
1999, ApJ, 512, 672, astro-ph/9807086

Microlensing by Multiple Planets in High Magnification Events
B. Scott Gaudi, *R.M. Naber* & P.D. Sackett
1998, ApJLett, 502L, 33, astro-ph/9803282

The 1995 Pilot Microlensing Campaign of PLANET: Searching for Anomalies through Precise, Rapid Round-the-Clock Monitoring
M. Albrow, *J.-P. Beaulieu*, P. Birch, J.A.R. Caldwell, S. Kane, R. Martin, J. Menzies, *R.M. Naber*, J.-W. Pel, K. Pollard, P.D. Sackett, K.C. Sahu, *P. Vreeswijk*, A. Williams & M. Zwaan (PLANET Collaboration)
1998, ApJ, 509, 687, astro-ph/9807299

Red Clump Morphology as Evidence Against a New Intervening Stellar Population as the Primary Source of Microlensing Toward the LMC
J.P. Beaulieu and Penny D. Sackett
1998, AJ, 116, 209, astro-ph/9710156

Does the Milky Way have a Maximal Disk?
Penny D. Sackett
1997, ApJ, 483, 103, astro-ph/9608164

The Structure of Dark Halos: Model-Independent Information from HI Rotation Curves
Penny D. Sackett
1997, PASA, 14, 11

Dust and Infrared Imaging of Polar Ring Galaxies
M. Arnaboldi, K.C. Freeman, P.D. Sackett, L.S. Sparke, and M. Capaccioli
1995, P&SS, 43, 1377

The Orientation of Spin Vectors of Galaxies in the Ursa Major Filament
Cheongho Han, Andrew Gould, and Penny D. Sackett
1995, ApJ, 445, 46, astro-ph/9408022

The Flattened Dark Halo of Polar Ring Galaxy NGC 4650A: A Conspiracy of Shapes?
P. D. Sackett, H.-W. Rix, B. J. Jarvis, and K. C. Freeman
1994, ApJ, 436, 629, astro-ph/9406015

A Faint Luminous Halo that May Trace the Dark Matter around Spiral Galaxy NGC 5907
P. D. Sackett, H. L. Morrison, P. Harding, and T. A. Boroson
1994, Nature, 370, 441, astro-ph/9407068

A Neutral Hydrogen Survey of Polar-Ring Galaxies: I. The Green Bank Northern Sample
O-G. Richter, P. D. Sackett, and L. S. Sparke
1994, AJ, 107, 99, astro-ph/9308023

MACHOs in a Flattened Halo
Penny D. Sackett and Andrew Gould
1993, ApJ, 419, 648, astro-ph/9304023

New Observations and a Photographic Atlas of Polar-Ring Galaxies
Bradley C. Whitmore, Ray A. Lucas, Douglas B. McElroy, Thomas Y. Steiman-Cameron, Penny D. Sackett, and Rob P. Olling
1990, AJ, 100, 1489

The Dark Halo of the Polar Ring Galaxy NGC 4650A
Penny D. Sackett and Linda S. Sparke
1990, ApJ, 361, 408

Radio Observations of Saturn as a Probe of Its Atmosphere and Cloud Structure
F. H. Briggs and P. D. Sackett
1989, Icarus, 80, 77

High Temperature Expansions to Fifteenth Order
Ralph Z. Roskies and P. D. Sackett
1987, J. Stat. Phys., 49, 447

Λ-Parameters for Asymmetric Lattice Gauge Theories with Fermions
P. D. Sackett
1983, Nuc. Phys., B227, 50

Lecture Series

Searching for Unseen Planets via Occultation and Microlensing
Penny D. Sackett
1999, in Planets outside the Solar System: Theory and Observations, Eds. J.-M. Mariotti & D. Alloin (NATO-ASI Series: Kluwer) 189, astro-ph/9811269

Book Chapters

Endangered Elements: Conserving the Building Blocks of Life
Penny D. Sackett
in *Creating a Sustainable and Desirable Future*
2014, R. Costanza and I. Kubiszewski (eds), World Scientific Singapore

Books

Microlensing 2000: A New Era of Microlensing Astrophysics
eds. John W. Menzies & Penny D. Sackett
2001, ASP Conf. Series, volume 239

Warped Disks and Inclined Rings around Galaxies
eds. Stefano Casertano, Penny D. Sackett, and Franklin H. Briggs
1991 (CUP: Cambridge)

Projects in Scientific Computing
Penny D. Sackett, Scientific Editor
1987, Pittsburgh Supercomputing Center Annual Magazine

Book Reviews

Surely You Must Be Joking, Mr. Feynman (Review)
Penny D. Sackett
1985, Am. J. Phys., 53, 12, 1214

The New Astronomy (Review)
Penny D. Sackett
1984, Am. J. Phys., 52, 11, 1051

Technical Reports and Communications: Astrophysics

Back home on Stromlo!
P.D. Sackett
2003, J. British Astron. Assoc., 113, 74

Optical observations of GRB 990627
E. Rol, E. Palazzi, N. Masetti, E. Pian, F. Frontera, T. J. Galama, *P. M. Vreeswijk*, J. van Paradijs, C. Kouveliotou, G. Bakos, K. Sahu, P. Sackett, J. Menzies, L. Nicastro & E. Costa
1999, GCN, 358, 1

GRB 990510 optical observations
T. J. Galama, *P. M. Vreeswijk*, E. Rol, N. Tanvir, E. Palazzi, E. Pian, N. Masetti, F. Frontera, K. Pollard, J. Menzies, P. Sackett, K. Sahu, J. van Paradijs, C. Kouveliotou
1999, GCN, 313, 1

GRB 990510 optical observations
P. M. Vreeswijk, T. J. Galama, E. Rol, K. Pollard, J. Menzies, P. Sackett, K. Sahu, J. van Paradijs, C. Kouveliotou
1999, GCN, 310, 1

Planet Detection via Microlensing
Penny D. Sackett
1997, ESO Document: SPG-VLTI-97/002, Appendix C of Final Report of the ESO Working Group on the Detection of Extrasolar Planets, astro-ph/9709269

Galactic structure: strange colours peek from dark halo
Penny D. Sackett
1997, Nature, News & Views, 387, 124

Supernova 1994P in UGC 6983
P. Sackett, A. Gould, A. Filippenko, M.W. Richmond, and T. Matheson
1994, IAU Circular 5989, 1

Published Conference Proceedings

The Frequency of Hot Jupiters in the Galaxy
Daniel D. R. Bayliss and Penny D. Sackett
2011, EPJ Web of Conferences, 11: Detection and Dynamics of Transiting Exoplanets, eds. F. Bouchy, R. Daz and C. Moutou

HAT-South: A Global Network of Southern Hemisphere Automated Telescopes to Detect Transiting Exoplanets
G. Bakos, C. Afonso, T. Henning, A. Jordán, M. Holman, R.W. Noyes, , P.D. Sackett, D. Sasselov, G. Kovcs, Z. Csubry, and A. Pl,
2009, IAU Symposium 253: Transiting Planets, eds. F. Pont, D. Sasselov and M. Holman, p 354-7

Transits against Fainter Stars: The Power of Image Deconvolution
P. D. Sackett, M. Gillon, *D. D. R. Bayliss D. T. F. Weldrake*, & *B. Tingley*
2009, IAU Symposium 253: Transiting Planets, eds. F. Pont, D. Sasselov and M. Holman, p 55-61, arXiv 0903.1329

SuperLupus: A Deep, Long Duration Transit Survey
D. D. R. Bayliss, P. D. Sackett, & *D. T. F. Weldrake*
2009, IAU Symposium 253: Transiting Planets, eds. F. Pont, D. Sasselov and M. Holman, p 333-5, arXiv 0807.0469

The SkyMapper Transit Survey
D. D. R. Bayliss & P. D. Sackett
2007, ASP Conf Series 366: Transiting Extrapolar Planets, eds. C. Afonso, D. Weldrake, and Th. Henning, p 370

Searching for Planetary Transits in Globular Clusters - 47 Tucanae and ω Centauri
D. T. F. Weldrake, P. D. Sackett & T. J. Bridges
2007, ASP Conf Series 366: Transiting Extrapolar Planets, eds. C. Afonso, D. Weldrake, and Th. Henning, p 289

Searching for Planetary Transits in the Lupus Galactic Plane
D. T. F. Weldrake, *D. D. R. Bayliss*, P. D. Sackett, M. Bessell & *B. Tingley*
2007, ASP Conf Series 366: Transiting Extrapolar Planets, eds. C. Afonso, D. Weldrake, and Th. Henning, p 90

Detecting Solar-System Gas Giant Analogs in Reflected Light with ELTs
Penny D. Sackett
2006, IAU Symposium 232: The Scientific Requirements for Extremely Large Telescopes, eds. P. Whitelock, B. Liebundgut & M. Dennefeld, p 356

Results from Microlensing Searches for Extrasolar Planets (Invited Review) Penny D. Sackett
2004, IAU Symposium 202: Planetary Systems in the Universe, ed. A. Penny, p 44

Giant Planets and Variable Stars in 47 Tucanae – A progress report of a comprehensive ground-based search
David T.F. Weldrake, Penny D. Sackett & Terry J. Bridges
2003, IAU Symposium 219: Stars as Suns, eds. A.K. Dupree and A. Benz, astro-ph/0309476

Examining stellar atmospheres via microlensing
C. Thurl, P. D. Sackett, & P. H. Hauschildt
2004, Astronomische Nachrichten, 325, 3, p.247

Microlensing in M31: Preliminary lightcurves from MEGA
J. de Jong, P. D. Sackett, K. Kuijken, R. Uglesich, A. Crotts, W. Sutherland
2001, in the proceedings of the STScI symposium "The Dark Universe", astro-ph/0107560

Microlensing and the Physics of Stellar Atmospheres
Penny D. Sackett
2001, in Microlensing 2000: A New Era of Microlensing Astrophysics, eds. J.W. Menzies and P.D. Sackett, ASP Conf Series, vol 239, 213, astro-ph/0004237

Microlensing in M31 – The MEGA Survey's Prospects and Initial Results
A. Crotts, R. Uglesich, A. Gould, G. Gyuk, P. Sackett, K. Kuijken, W. Sutherland, & L. Widrow
2001, in Microlensing 2000: A New Era of Microlensing Astrophysics, eds. J.W. Menzies and P.D. Sackett, ASP Conf Series, vol 239, 318, astro-ph/0006282

PLANET Observations of Anomalous Microlensing Events
J. Menzies, M. D. Albrow, *J.-P. Beaulieu*, J. A. R. Caldwell, D. L. DePoy, *B.S. Gaudi*, A. Gould, J. Greenhill, K. Hill, S. Kane, R. Martin, *M. Dominik*, *R.M. Naber*, R. W. Pogge, K. R. Pollard, P. D. Sackett, K. C. Sahu, P. Vermaak, R. Watson, A. Williams (PLANET)
2001, Microlensing 2000: A New Era of Microlensing Astrophysics, eds. J.W. Menzies and P.D. Sackett, ASP Conf Series, vol 239, 109

Microlensing Constraints on the Frequency of Jupiter Mass Planets
B. Scott Gaudi, M. D. Albrow, Jin H. An, *J.-P. Beaulieu*, J. A. R. Caldwell, D. L. DePoy, *M. Dominik*, A. Gould, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, R. W. Pogge, K. R. Pollard, P. D. Sackett, K. C. Sahu, P. Vermaak, R. Watson, A. Williams (PLANET)
2001, Microlensing 2000: A New Era of Microlensing Astrophysics, eds. J.W. Menzies and P.D. Sackett, ASP Conf Series, vol 239, 135, astro-ph/0004269

The 24-Hour Night Shift: Astronomy from Microlensing Monitoring Networks
Penny D. Sackett
2001, **Invited Targeted Talk** at Gravitational Lensing: Recent Progress and Future Goals,ASP Conf Series 237, eds. T.G. Brainerd and C.S. Kochanek, 227 astro-ph/0001048

Results from Microlensing Searches for Extrasolar Planets
Penny D. Sackett
2000, **Invited Review** "Planetary Systems in the Universe: Observation, Formation and Evolution," (IAU Symposium 202), Editors A. Penny, P. Artymowicz, A.-M. Lagrange, and S. Russell, ASP Conf Series, astro-ph/0011128

Variable Star Research by the PLANET Collaboration
M. D. Albrow, *J.-P. Beaulieu*, J. A. R. Caldwell, D. L. DePoy, *B. S. Gaudi*, A. Gould, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, *R. M. Naber*, R. W. Pogge, K. R. Pollard, P.D. Sackett, K. C. Sahu, P. Vermaak, R. Watson, A. Williams (PLANET)
2000, in The Impact of Large-Scale Surveys on Pulsating Star Research, IAU 176, eds. L. Szabados and D. Kurtz, ASP Conf Series 203, 25

Planetary Microlensing: Present Status and Long-term Goals
Penny D. Sackett
1999, **Invited Review** at VLT Opening Symposium, Antofagasta, Chile, March 1999. ESO Astrophysics Symposia (Springer-Verlag), 436, astro-ph/9907185

Weighing the Stellar Content of NGC 5907's Dark Matter Halo
Michael C. Lui, Francine R. Marleau, James R. Graham, Penny D. Sackett & Steve Zepf
1998, in the Proceedings of the 19th Texas Symposium on Relativistic Astrophysics and Cosmology, eds. J. Paul, T. Montmerle & E. Aubourg (CEA Saclay) 285

The Shape of Dark Matter Halos
Penny D. Sackett
1999, **Invited Review**, in Galactic Dynamics, in Proceedings of the Rutgers 1998 Conference eds. D. Merritt, J.A. Sellwood and M. Valluri, ASP Conf Series 182, astro-ph/9903420

1997 PLANET Monitoring of Anomalous Events: First Detection of Limb Darkening via Microlensing
P.D. Sackett and M. Albrow, *J.-P. Beaulieu*, J.A.R. Caldwell, *M. Dominik*, J. Greenhill, Kym Hill, S. Kane, R. Martin, J. Menzies, *R.M. Naber*, J.-W. Pel, K. Pollard, K.C. Sahu, P. Vermaak, R. Watson, A. Williams (PLANET Collaboration)
1998, in the Proceedings of the 4^{th} Microlensing Workshop, Paris

Final Results from the 1995 Pilot Monitoring Campaign of PLANET
P.D. Sackett and M. Albrow, *J.-P. Beaulieu*, P. Birch, J.A.R. Caldwell, S. Kane, R. Martin, J. Menzies, *R.M. Naber*, J.-W. Pel, K. Pollard, K.C. Sahu, *P. Vreeswijk*, A. Williams, M. Zwaan (PLANET Collaboration)
1998, in the Proceedings of the 4^{th} Microlensing Workshop, Paris

The PLANET Collaboration: Probing Lensing Anomalies
M. Albrow, *J.-P. Beaulieu*, P. Birch, J.A.R. Caldwell, J. Greenhill, K. Hill, S. Kane, R. Martin, J. Menzies, *R.M. Naber*, J.-W. Pel, K. Pollard, P.D. Sackett, K.C. Sahu, *P. Vreeswijk*, R. Watson, A. Williams, M. Zwaan (PLANET Collaboration)
1997, **Invited Presentation** by P.D. Sackett, in Variable Stars and Astrophysical Returns of Microlensing Surveys, eds. R. Ferlet, J.-P. Maillard & B. Raban (Editions Frontieres: Cedex France) 135, astro-ph/9610128

Galactic Parameters
Penny D. Sackett
1997, in Proceedings of the 3^{rd} International Workshop on Gravitational Microlensing Surveys, South Bend, Indiana

Results from the PLANET Collaboration
Penny D. Sackett
1997, in Proceedings of the 3^{rd} International Workshop on Gravitational Microlensing Surveys, South Bend, Indiana

The PLANET Collaboration
M. Albrow, P. Birch, J. Caldwell, R. Martin, J. Menzies, J.-W. Pel, K. Pollard, P. D. Sackett, K. Sahu, *P. Vreeswijk*, A. Williams, and M. Zwaan (PLANET Collaboration)
1996, (presented by P.D. Sackett) in Astrophysical Applications of Gravitational Lensing, IAU 173, eds. C. Kochanek and J. Hewitt (Dordrecht: Kluwer), 227

The Distribution of Dark Mass in Galaxies: Techniques, Puzzles, and Implications for Lensing
Penny D. Sackett
1996, **Invited Review** in Astrophysical Applications of Gravitational Lensing, IAU 173, eds. C. Kochanek and J. Hewitt (Dordrecht: Kluwer) 165, astro-ph/9508098

The PLANET Collaboration: Current Status and Future Prospects
Penny D. Sackett
1996, in the Proceedings of the 2^{nd} Microlensing Workshop, Orsay, France

Can a Dark Disk Explain both the LMC and Bulge Events?
Penny D. Sackett
1995, in the Proceedings of the 1^{st} Microlensing Workshop, Livermore, CA

A Faint Luminous Halo that May Trace the Dark Matter around Spiral Galaxy NGC 5907
Heather L. Morrison, Penny D. Sackett, Paul A. Harding, and Todd Boroson
1995, in Dark Matter, AIP 336, 157

Another Flattened Dark Halo: Polar Ring Galaxy A0136-0801
Penny D. Sackett and Richard W. Pogge
1995, in Dark Matter, AIP 336, 141, astro-ph/9412011

Kinematics of Polar-Ring Galaxies

Penny D. Sackett

1991, in Warped Disks and Inclined Rings around Galaxies, eds. Stefano Casertano, Penny D. Sackett and Franklin H. Briggs (CUP: Cambridge) 73

Shape of the Dark Halo of Polar Ring Galaxy NGC 4650A

Penny D. Sackett and Linda S. Sparke

1989, in Dynamics and Interactions of Galaxies, ed. R. Wielen (Springer-Verlag: Heidelberg) 367

Does Saturn Contain Sulfur Far in Excess of Solar Abundance?

P. D. Sackett and F. H. Briggs

1988, in The Formation and Evolution of Planetary Systems, eds. H.A. Weaver, F. Paresce, and L. Danly (STScI: Baltimore) 29

Popular and Trade Articles

Huge Cosmic Lenses

Penny D. Sackett

2001, **Invited Feature Review**, EuroPhysics News, Nov/Dec, 226

Op Zoek naar Andere Zonnestelsels: Sterren en donkere objekten als microlenzen in de Melkweg

Penny D. Sackett

1998, Zenit, 5, 203

Centers of Supercomputing: Science at the Pittsburgh Supercomputing Center

Ralph Z. Roskies and Penny D. Sackett

1998, International J. of Supercomputing App., 2, 1

A Computer-Generated Cosmic Portfolio

Penny D. Sackett

1983, Science News, 124, 18, 282, and many shorter articles in the June-August 1983 issues

Is Physics a 'Hard Science'?

Penny D. Sackett

1983, Pitt Magazine, 37, 3, 11