Climate Resource

Victorian emissions budgets

Report for Victorian Government Department of Energy, Environment and Climate Action

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Executive summary

Purpose of this report

The Climate Change Act 2017 requires the Victorian Government to set an interim emission reduction target for 2035. The Government must receive advice on the target from an Independent Expert Panel. This paper supports that process by deriving greenhouse gas (GHG) emissions budgets for Victoria consistent with the Paris Agreement goal of keeping warming well below 2°C and pursuing efforts to limit warming to 1.5°C.

The paper uses the most up-to-date carbon budgets in the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6) as a starting point and presents options in relation to the key subjective decisions that must be made to derive an emissions budget for Victoria. These include: the temperature goal of the global budget chosen as a starting point (e.g. 2°C or 1.5°C, with or without overshoot); how to calculate Australia's fair share of a global budget (e.g. based on population, contraction and convergence or other methods); and how to calculate Victoria's fair share of an Australian budget. For each of these decisions, the paper highlights the key considerations and, where possible, points to international practice.

Key updates since Victoria's 2030 target was set

The approach outlined in this paper builds on work undertaken to develop Victorian emissions budgets adopted by Victoria's first Independent Expert Panel (the Combet Panel) in 2019[1] to inform the setting of a 2030 interim emission reduction target. It uses the same overall approach but incorporates updates to take into account:

- Changes in the science and mitigation pathways as assessed in the IPCC AR6 Report, particularly the 2021 Working Group I (WG1) and 2022 Working Group 3 (WG3) contributions; and
- The evolving global climate policy landscape and how this relates to key choices facing the Panel about the temperature goal for the emissions budget; the share of a global budget allocated to Australia; and the share of an Australian budget allocated to Victoria.

Key changes of note since the report prepared for the Combet Panel in 2019 are:

- The latest global carbon budgets in IPCC AR6 are slightly larger than those in the IPCC Special Report on 1.5°C of warming, which were used by the Combet Panel. This is due to a revised treatment of Earth System feedbacks, a slight reduction in the

[1] See Meinshausen et all (2019) *Greenhouse Gas Emissions Budgets for Victoria*. Accessed: 24 Jan 2023 https://www.climatechange.vic.gov.au/__data/assets/pdf_file/0016/421702/Greenhouse-Gas-Emissions-Budgets-for-Victoria.pdf and
Meinshausen (2019) *Deriving a global 2013-2050 emission budget to stay below 1.5°C based on the IPCC Special Report on 1.5°C.* Accessed: 24 Jan 2023 https://www.climatechange.vic.gov.au/__data/assets/pdf_file/0018/421704/Deriving-a-1.5C-emissions-budget-for-Victoria.pdf.

estimate of historical warming, and a reduction in the uncertainty of the sensitivity of the climate system to carbon dioxide emissions.

- The world is increasingly turning its focus onto budgets consistent with 1.5°C (often with slight overshoot – see below) and budgets premised on limiting warming to 2°C are increasingly viewed as being inconsistent with The Paris Agreement.
- A number of other jurisdictions have used an equal per capita approach to estimate their share of a global emissions budget, such as Germany, Ireland and Denmark – which would, if applied to Australia, equate to only about a third of emission allowances compared to the previous analysis and effort shares usually applied in the Australian context.

Emissions budgets for Victoria

The Panel requested that two global budgets be used as a starting point for estimating emissions budgets for Victoria – one consistent with a 50% chance of limiting temperature increases to below 1.5°C, and one consistent with a 50% chance of limiting peak temperatures to below 1.6°C. The former can be considered to be a "1.5°C without overshoot" budget, while the latter can be considered to be both a "1.5°C with slight overshoot" budget[2] and a "well below 2°C" budget[3]. Overshoot is explained in the box below.

Explaining the concept of 'overshoot'

A key factor determining the size of a global 1.5°C budget is whether this temperature goal will be achieved with or without 'overshoot'.

- A '1.5°C without overshoot' budget is smaller, i.e. implies less cumulative emissions. This in turn implies lower climate impacts, with temperature increases staying below 1.5°C.
- A '1.5°C with overshoot' budget is larger, i.e. implies more cumulative emissions. Temperatures peak above 1.5°C before returning to below 1.5°C by 2100. This higher temperature peak means there is a risk of higher climate impacts. Implicit in these budgets is the assumption that some CO_2 emissions will be removed from the atmosphere in the second half of the 21st century to lower warming back below 1.5°C by 2100. The effort sharing of who will undertake those permanent CO_2 removals is an important issue, but not part of this paper.

Among jurisdictions that emphasise the 1.5°C goal, it is more common for targets to be consistent with a '1.5°C with overshoot budget', with only a few in line with a 1.5°C without overshoot budget.

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[2] Most IPCC mitigation scenarios labelled as 1.5°C include some limited (around 0.1°C) of overshoot, which is why a 1.6°C budget has been chosen as a proxy for a '1.5°C budget with overshoot' in this exercise.
[3] There is no international consensus on the definition of "well below 2°C". However, the literature suggests that this could be a 90% chance of limiting temperature increases to 2°C. This is roughly equivalent to a 50% chance of limiting temperature increases to 1.6°C. Therefore, a budget with a 50% chance of limiting temperature increases to 1.6°C could also be considered to be a "well below 2°C" budget.

This paper presents the global carbon budgets selected as starting points, and steps through the conversion of these into global GHG emissions budgets using a methodology consistent with that used for the Combet Panel budgets.

The Wilder Panel then requested that two approaches be used to determine the share of those global budgets notionally assigned to Australia and then Victoria's share of those notional Australian budgets:

- a (modified) contraction and convergence approach, consistent with the approach used by the Garnaut Review (2008), The Climate Change Authority (2014) and the Combet Panel (2019)
- an equal per capita approach, as has been adopted by some other jurisdictions.

Victoria's historical emissions, based on the latest official emissions inventory containing data up to 2020, are then subtracted to provide a budget for Victoria's future emissions for 2021-2050[4]. This results in four Victorian emissions budgets (Table ES.1).

Table ES.1 – Victorian emissions budgets for 2021 – 2050 based on different assumptions about Australia's fair share of the global emissions budget and Victoria's fair share of the Australian emissions budget.

Budgets applying a "modified contraction and convergence" approach to budget shares			
Global budget	**Share of global budget assigned to Australia**	**Share of Australian budget assigned to Victoria**	**Victorian emissions budget 2021 - 2050 ($MtCO_2eq$)**
1.5°C @ 50% ‘1.5°C without overshoot’	0.97%	22.7%	1016
1.6°C @ 50% ‘1.5°C with overshoot’ and ‘well below 2°C’			1368
Budgets applying an "equal per capita" approach to budget shares			
Global budget	**Share of global budget assigned to Australia**	**Share of Australian budget assigned to Victoria**	**Victorian emissions budget 2021-2050 ($MtCO_2eq$)**
1.5°C @ 50% ‘1.5°C without overshoot’	0.33%	25.5%	-205
1.6°C @ 50% ‘1.5°C with overshoot’ and ‘well below 2°C’			-71

We note that the emissions budgets derived based on an equal-per-capita approach have already been used up by 2021.

[4] We note that the Victorian Government has committed to legislate an earlier net zero emissions date of 2045. At the time of writing of this report, this has not yet been implemented. While our analysis uses a net zero date of 2050, this difference does not affect any presented results on the remaining carbon budget. An earlier net-zero year for Victoria will not imply a smaller or larger carbon budget up to the point of net-zero emissions, although it will change whether Victoria is consistent with those budgets or not.

1 Introduction

The Victorian Government must set an interim emissions reduction target for 2035. As part of the target setting process, an Interim Targets Independent Expert Panel (the Panel) is providing advice to the Government. This paper supports that process by outlining the greenhouse gas (GHG) emissions budgets for Victoria consistent with keeping warming well below 2°C and pursuing efforts to limit warming to 1.5°C.

A global emissions budget is a science-based estimate of the cumulative amount of GHGs that can be emitted for a given probability (e.g., 50%, 67% or 90%) of limiting global mean temperature rise to below a given level, such as 1.5°C. An emissions budget for Victoria can be derived from the global emissions budget by making key assumptions about Victoria's fair share.

The approach outlined in this paper builds on the work undertaken to develop the emissions budgets adopted by Victoria's first Independent Expert Panel (the Combet Panel) in 2019, using the same overall approach but incorporating updates to take into account:

- Changes in the science and mitigation pathways as assessed in the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment (AR6) Report, particularly the 2021 Working Group I (WG1) and 2022 Working Group 3 (WG3) contributions; and
- The evolving global climate policy landscape relevant to the choices facing the Panel.

This paper outlines:

- Why emissions budgets are used to inform jurisdictions' emissions reductions targets;
- Key policy choices relevant to the selection of global emissions budgets;
- Steps followed to translate the global emissions budget(s) into a scope consistent with Victoria's Climate Change Act 2017;
- The approach to determining the share for Australia; and
- The approach to determining the share for Victoria.

2 Use of emissions budgets to inform target setting

The world has a finite emissions budget consistent with limiting warming to 1.5°C. The emissions budget constraint exists because the majority of human-induced climate change is due to carbon dioxide (CO_2) emissions and there is a near linear relationship between cumulative CO_2 emissions and induced changes in average global surface temperature (see [5,6] and further discussion in the advice prepared for the Combet Panel in 2019[7]). To limit global warming, CO_2 emissions must be reduced to net zero.

Emissions budgets build on this CO_2-focused relationship and are an important tool in guiding emissions reduction targets. They also include other GHGs, e.g. methane and nitrous oxide, by making use of the close correlation between cumulative CO_2 and cumulative GHG emissions in future mitigation scenarios. While there is some flexibility as to how much non-CO_2 GHG emissions are reduced, most mitigation scenarios from the scientific literature agree on the level of reductions that go approximately hand in hand with CO_2 reductions. Hence, even though the cumulative carbon to temperature relationship is only strictly valid for CO_2, the fact that there are only a few decades left to reach net-zero emissions and there is a relatively strong alignment between CO_2 and non-CO_2 emissions allows us to use CO_2 emission budgets to derive GHG emission budgets.

As a policy instrument, emissions budgets play two key roles. First, they allow an assessment of the extent to which interim emissions targets for Victoria, or any other jurisdiction, are consistent with it contributing to a global goal of 1.5°C or well below 2°C. Given this, the emissions budget for Victoria should be updated as new climate science emerges. It is timely to review Victorian emissions budgets now in light of the IPCC's AR6 report, which provides an up-to-date assessment of the latest climate science and physical understanding of the climate system and climate change.

Secondly, emissions budgets make clear the trade-offs between reducing emissions early or waiting until later. If cumulative emissions in Victoria must be kept within a given budget, the choice of interim 5-yearly targets and the policies implemented to deliver on those targets determine the pace at which the emissions budget is consumed. This affects the transition pathway the economy pursues and the allocation of costs and benefits over time. Faster emissions reductions in the early years using known technologies give more time for emissions reductions from sectors of the economy for which we do not yet have commercial-scale low emissions technologies. The converse is also true of course - slower

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[5] Allen, M. R., Frame, D. J., Huntingford, C., Jones, C. D., Lowe, J. A., Meinshausen, M., & Meinshausen, N. (2009). Warming caused by cumulative carbon emissions towards the trillionth tonne. *Nature*, *458*(7242), 1163.

[6] Meinshausen, M., Meinshausen, N., Hare, W., Raper, S. C. B., Frieler, K., Knutti, R., Frame, D. J., & Allen, M. R. (2009). Greenhouse-gas emission targets for limiting global warming to 2°C. *Nature*, *458*(7242), 1158-1162. https://doi.org/10.1038/nature08017

[7] Meinshausen et al, (2019) Greenhouse Gas Emissions Budgets for Victoria, available at https://www.climatechange.vic.gov.au/climate-action-targets

emissions reductions in the period to 2035 require far more rapid reductions between 2035-2050 to stay within Victoria's budget.

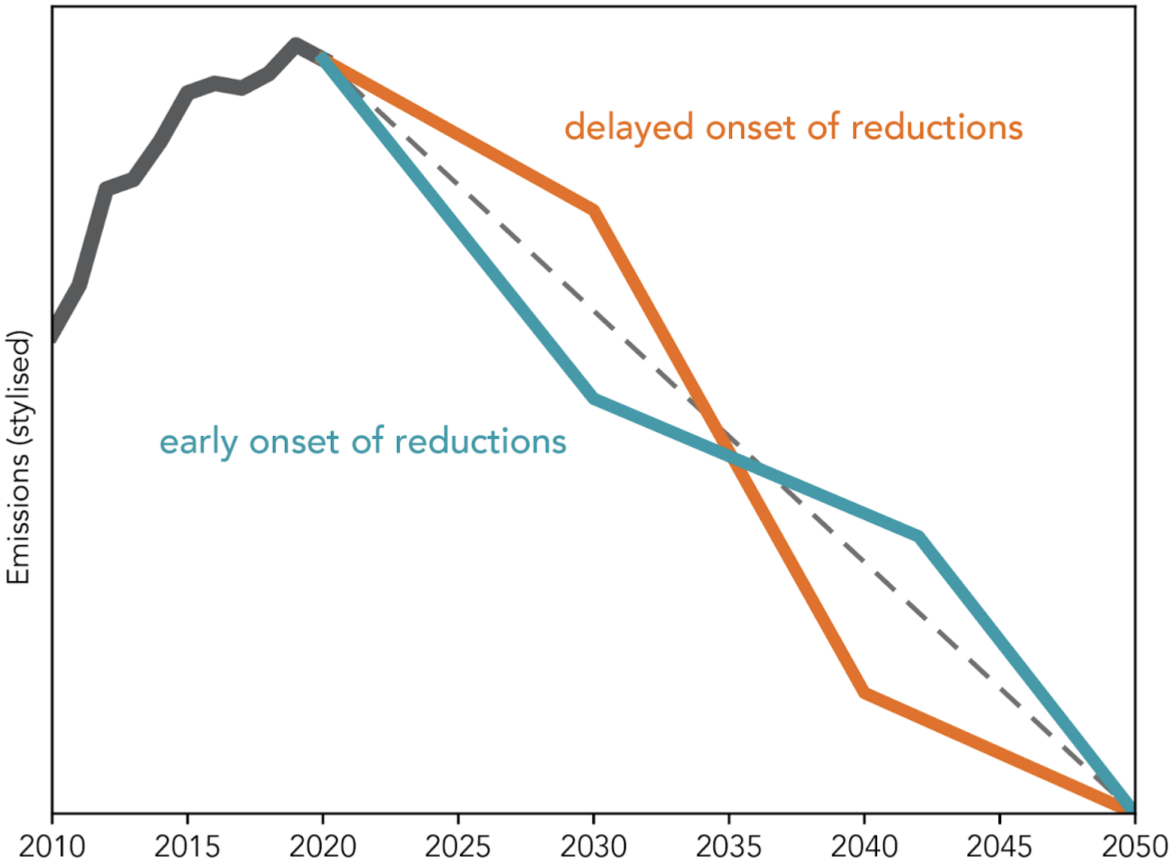

Figure 1 - Stylised illustration of the impact of early reductions compared to delayed reductions in emissions. Both pathways have the same cumulative emissions, i.e., they are consistent with the same emissions budget. The pathway that features early reductions has a slower rate of reductions at later points in time. Conversely, the pathway that has a delayed start to reductions features much more rapid cuts between 2030 and 2040. The dashed grey line is a straight line from 2020 emissions levels to net zero in 2050.

Emissions budgets are used in Australia and globally to inform emission reduction targets. In Australia, the Garnaut Review[8], the Climate Change Authority[9], and the Combet Panel[10] in Victoria used emissions budgets to guide their recommended targets. Internationally, policy makers in other jurisdictions including the UK, France, Denmark, New Zealand and the USA all reference emissions budgets as influencing their approach to emissions targets for 2030, 2050 or other interim periods. Courts have also referred to emissions budgets in landmark decisions - such as the German Federal Constitutional Court's 2021 ruling that the Federal Climate Change Act was partially unconstitutional because the annual emissions allowed

[8] Garnaut, R. (2008). *The garnaut climate change review*. Cambridge, England: Cambridge University Press.
[9] Australian Government Climate Change Authority (2014), available at https://www.climatechangeauthority.gov.au/sites/default/files/2020-06/Target-Progress-Review/Targets%20and%20Progress%20Review%20Final%20Report.pdf
[10] Meinshausen et al, (2019) Greenhouse Gas Emissions Budgets for Victoria, available at https://www.climatechange.vic.gov.au/climate-action-targets

until 2030 gave insufficient regard to what is required in subsequent decades to limit warming to well below 2°C or 1.5°C.[11]

Other jurisdictions that make use of budgets in guiding their emissions reductions commitments and policies adopt a range of approaches (as described in Appendix 2). Many of those that set five-yearly emissions reductions targets or carbon budgets, are informed to differing degrees by both[12]:

- Global carbon budgets consistent with the Paris Agreement temperature goal (described as a top-down approach, or a “climate science carbon budget”); and
- The budgets assessed as delivering the emissions reductions targets in policy or legislation (e.g. net-zero by 2050) over multiple sectors (a bottom up approach, or a “climate policy carbon budget”).

The Combet Panel started its consideration of the Victorian emissions budget by deriving a climate science budget (top-down approach), which we also follow.

3 Key policy choices for the selection of a global emission budget

Deriving a global emissions budget requires making choices about:

- The temperature target;
- The probability of achieving this temperature target; and
- Whether this temperature target will be achieved with or without overshoot.

3.1 The temperature target

Art. 2.1(a) of the 2015 Paris Agreement states the goal of:

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

In the past, different interpretations of Art 2.1 (a) have been proposed. One interpretation was that the Paris Agreement presents a choice between two temperature goals: a “well below 2°C” limit as well as a 1.5°C limit. However, more and more it is understood as a single goal of pursuing efforts to limit the temperature increase to 1.5°C, potentially with an

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[11] German High Court decision here: https://www.bundesverfassungsgericht.de/SharedDocs/Entscheidungen/DE/2021/03/rs20210324_1bvr265618.html and also A. Bauser (2021) German Law Journal , Volume 22 , Issue 8 DOI: https://doi.org/10.1017/glj.2021.81

[12] McGuire et al,. Discussion Paper: The role of carbon budgets in translating the Paris Agreement into national climate policy, MaREI, Environmental Research Institute (ERI) at University College Cork, available at https://www.marei.ie/wp-content/uploads/2020/10/Discussion-Paper_The-role-of-carbon-budgets-in-translating-the-Paris-Agreement-into-national-climate-policy.pdf

overshoot, while simultaneously staying "well-below 2°C" peak temperature at all times.[13] The focus on the 1.5°C temperature level and the move away from 2°C was heightened by the Glasgow Climate Pact in 2021 which states[14]:

> *"…the impacts of climate change will be much lower at the temperature increase of 1.5 °C compared with 2 °C, and resolves to pursue efforts to limit the temperature increase to 1.5 °C"*

This language has also been confirmed by the 2022 Sharm-el-Sheikh implementation Plan[15]. This reflects international policymakers' shifting emphasis towards limiting warming to 1.5°C. It is evident in the increasing level of climate ambition globally, including the growing number of countries with targets for net zero emissions by 2045, 2050 (or 2060 and 2070 in the case of China, and India respectively). Since the 2015 Paris Agreement and as of September 2022[16], 169 Parties have updated or submitted new 2030 mitigation goals in their nationally determined contributions (NDCs) and 81 have put forward longer-term targets, many of which include commitments to net zero by mid-century. Peak warming of just below 2°C (at higher than 50% probability) is now projected, for the first time, if all NDCs and longer-term targets are met in full and on time[17]. The world is still far from a "well-below" 2°C trajectory or an emissions trajectory in line with 1.5°C (particularly due to insufficient 2030 NDCs), but most individual countries with net-zero targets are showing at least some leadership. If the 2030 NDCs become more ambitious, the net-zero long-term targets are achieved, and similar targets are adopted by the rest of the world (who are yet to adopt these net-zero targets), the world will inch closer to 1.5°C.

Decisions in landmark court cases have also placed strong emphasis on the 1.5°C target. The Dutch Supreme Court's Urgenda judgement in 2019 notes, amongst other things, that it has been recognised "for some years that global warming should not be limited to a maximum of 2 °C to prevent dangerous climate change, but to a maximum of 1.5°C"[18].

In this context, the 2°C budget considered by the Combet Panel in 2019 could now be regarded as outdated.

3.2 The probability of achieving the temperature target

Any global emission budget should be associated with a specific probability of limiting warming to a specified level (e.g., 1.5°C or 2°C). These probabilities reflect the uncertainty

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[13] Art. 4.1 of the Paris Agreement refers to Art. 2 as a single temperature limit, and the argument is that Art. 2 in fact describes a single temperature limit. Rajamani Lavanya and Werksman Jacob (2018) "The legal character and operational relevance of the Paris Agreement's temperature goal", Phil. Trans. R. Soc. A., http://doi.org/10.1098/rsta.2016.0458

[14] https://unfccc.int/sites/default/files/resource/cop26_auv_2f_cover_decision.pdf

[15] https://unfccc.int/documents/624441

[16] https://unfccc.int/sites/default/files/resource/cma2022_04.pdf

[17] Meinshausen, M., Lewis, J., McGlade, C., Gütschow, J., Nicholls, Z., Burdon, R., Cozzi, L., & Hackmann, B. (2022). Realization of Paris Agreement pledges may limit warming just below 2 °C. *Nature*, *604*(7905), 304-309. https://doi.org/10.1038/s41586-022-04553-z

[18] Spier, J. 'The "Strongest" Climate Ruling Yet': The Dutch Supreme Court's Urgenda Judgment. *Neth Int Law Rev* 67, 319–391 (2020). https://doi.org/10.1007/s40802-020-00172-5

inherent in climate change projections. To assess these probabilities, the climate science and modelling communities consider the physics of the climate system and hundreds of different emissions reduction scenarios.

The higher the peak temperature level, the larger the remaining emission budget. In contrast, the higher the probability with which the temperature level is to be avoided, the smaller the remaining emission budget. As a consequence, an emissions budget associated with warming of 2°C with a high probability (say 75%) could be the same size as an emissions budget associated with achieving, say, 1.7°C with only a 50% chance.

However, this equivalence will not necessarily hold over time. As we move closer to the specified temperature level and learn more, our uncertainty estimates change. These changes in uncertainty estimates in turn affect the probabilities associated with different budgets and the budget estimates themselves. If we focus on budgets with a 90% chance of staying below a given threshold, then there is effectively a 90% chance that the real warming will eventually lie below that threshold. Thus, temperature targets based on a high likelihood to stay below a certain warming level also come with a high likelihood that the carbon budget will increase over time.[19]

This isn't to say that budgets that focus on a high probability of avoiding a temperature target are flawed, they can of course be a sensible way of mitigating the risks inherent in climate science and ongoing climate change. In particular, high probabilities hedge against the risk of the climate system reacting on the warm side compared to our understanding. But those high probability targets also come with a high probability that subsequent re-quantifications of the same emissions budget end up being larger and larger. We have already seen this play out in the changes between SR1.5 and AR6 (see Section 4.1). Between SR1.5 and AR6, the budgets for a 67% chance of staying below given temperature targets increased, largely because of the reduced uncertainty in how sensitive the earth system is to emissions. Put another way, if there is the choice between a 'high probability' below 2°C target and a 50% below 1.7°C target, the former target is more likely to be revised up than down while the latter target is equally likely to be revised up or down as science evolves hence is more likely to provide robust climate science advice to climate policy making.

The three most commonly used pieces of language that relate to the Paris Agreement's temperature target are "well-below 2°C", "1.5°C" limit, or "1.5°C with limited overshoot"[20].

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[19] To understand why this is so, consider the following: if we pick a budget such that it has a 90% chance of staying below a given warming threshold, we are effectively focusing on the 90th percentile of warming. However, our uncertainty estimates are likely to narrow over time. As a result, if we focus on the 90th percentile, and our uncertainty estimates narrow over time, then our median warming is effectively increasing over time. As a concrete example, at present, when we make projections, if we estimate that median warming is 1.5°C, then the 90th percentile of warming is around 1.9°C i.e. the difference between median warming and 90th percentile warming is around 0.4°C. If this narrows to say, 0.2°C in future, but we still target a 90th percentile warming of 1.9°C, then we are no longer targeting a median warming of 1.5°C, but instead we are targeting a median warming of 1.7°C. The narrowing uncertainty effect does not affect budgets that are based on a 50% chance, which are only affected by changes in our best-estimate.

[20] See Section 3.3 for a detailed discussion of overshoot.

These, and others, are outlined in Table 1, with some examples of approaches used elsewhere.

Table 1 - Temperature targets and probabilities - examples of options

Temperature target + assumptions about probability and overshoot	Comment
1) "Well-below 2°C" meaning 2°C with a (@) 67% chance	Many studies equate a 2°C target with 2°C @ 67%[21,22] Not in line with global emphasis on 1.5°C (more like 1.8°C of warming in the median)
2) "Well-below 2°C" meaning 2°C @ 83% chance	High chance that emission budgets will be revised upward (Section 3.2). Not likely to be considered in line with global emphasis on 1.5°C IPCC AR6 also reports carbon budgets for 83%
3) "Well-below 2°C" meaning, say, 1.6°C @ 50%	Aligning to a median temperature outcome likely avoids the issue of revision over time (Section 3.2). Such a framing can still provide a line of sight to higher probabilities today (e.g. 1.6°C @ 50% is roughly 2°C @ 90%, which has been suggested as the appropriate definition of well below in the literature[23]) There is no consensus on what the appropriate temperature level in between 1.5°C and 2°C should be. One guide is that the lower class of mitigation scenarios in IPCC WG3 peak at around 1.6°C. Some others - e.g. the German SRU[24] define "well-below 2°C" as a 67% chance to stay below 1.75°C (and also presents a 1.5°C target)
4) 1.5°C with limited overshoot, i.e., limiting peak temperatures below 1.6°C @ 50%	Consistent with many ambitious NDC and LT-LEDS targets that emphasise the 1.5°C goal (see Appendix 2) Most mitigation scenarios labelled as 1.5°C include some limited (around 0.1°C) overshoot.[25] The IEA Net-Zero scenario[26] peaks very close to 1.5°C as does the lowest of the IPCC WG1 assessed scenarios (SSP1-1.9), although some scenarios in IPCC WG3 have no overshoot. The inclusion of a small overshoot is also followed in IPCC AR6 WG3 The concept of "overshoot" relies on net-negative CO_2 and net-zero GHG emissions in the second-half of the century, with associated challenges for finding sustainable net-negative emissions options in Victoria

[21] Paragraph 33 in https://unfccc.int/sites/default/files/resource/cma2021_08_a03.pdf
[22] See e.g. Table 4.1 in UNEP Gap report 2021, available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/36995/EGR21_CH4.pdf
[23] Schleussner, C.-F., Ganti, G., Rogelj, J., & Gidden, M. J. (2022). An emission pathway classification reflecting the Paris Agreement climate objectives. *Communications Earth & Environment*, *3*(1), 135. https://doi.org/10.1038/s43247-022-00467-w
[24] Available at: https://www.umweltrat.de/SharedDocs/Downloads/EN/01_Environmental_Reports/2020_08_environmental_report_chapter_02.html
[25] https://wedocs.unep.org/bitstream/handle/20.500.11822/36995/EGR21_CH4.pdf
[26] https://www.iea.org/reports/net-zero-by-2050

5) 1.5°C without overshoot @ 50%	Consistent with Victoria adopting a global leadership position - few other jurisdictions have interim targets that are clearly in line with a 1.5°C @ 50% goal although there is some international precedent: • The German SRU[27] also derives targets @ 50% probability for 1.5°C of warming • Scotland's legislated targets for 2030 are stronger than what Scotland assessed as being required to meet the lower bound of the UK target range consistent with pathways with a 50% probability of limiting warming to 1.5°C.[28] Reduces the reliance on negative emissions technologies compared to a 1.5°C with overshoot budget. The time for strictly staying below "1.5°C" is rapidly closing and it is difficult to find feasible global pathways consistent with this. Without strongly enhanced mitigation action this decade at a global level, the current assessment is that 1.5°C without overshoot and with higher than 50% probabilities will not be achievable any more.

3.3 Overshoot

The derivation of a 1.5°C budget requires a choice about the extent to which it includes overshoot. All scenarios investigated by the IPCC AR6 WG1 report result in a best estimate warming of around 1.5°C in the early 2030s. The lowest emissions pathway (the SSP1-1.9 scenario) results in a temperature rise of around 1.5-1.6°C before decreasing again. The peak temperature of this lowest scenario is just above 1.55°C, so that the rounded value reported in AR6 WG1 is also 1.6°C, i.e., +0.1°C above the 1.5°C target level.

Similarly, in the IPCC AR6 WG3 Report, which investigates more than 1000 mitigation scenarios, there are very few mitigation scenarios that stay below 1.5°C at all times[29]. Almost all pathways that exhibit less than 1.5°C warming by the end of the century in the scientific literature imply an overshoot of around 0.1°C (with notable uncertainty in the level of overshoot due to the uncertain influence of aerosol precursor emissions on our climate).

Choosing to derive an emissions budget premised on overshoot matters for two key reasons:

- **The risk of higher climate impacts:** Impacts are higher at higher temperature levels, particularly if a tipping point is crossed. For example, there is no scientific certainty as to where exactly the threshold for triggering irreversible melting of the Greenland ice sheet sits. Some impacts can be reversible when returning to lower temperature levels (e.g. heat wave intensity), but others (loss of ecosystems, triggering Greenland ice sheet melt etc.) will not be.

[27] Available at: https://www.umweltrat.de/SharedDocs/Downloads/EN/01_Environmental_Reports/2020_08_environmental_report_chapter_02.html

[28] The UK Committee on Climate Change letter of advice to the Cabinet Secretary for Environment, Climate Change and Land Reform, 2020

[29] Natural variability could already cause individual years to exceed that threshold in the near future, here we refer to "at all times" on the basis of a 20-year rolling average

- **The challenge of net-negative emissions:** Reducing warming after overshooting the temperature target will likely require substantial amounts of net-negative carbon emissions, in other words removing CO_2 from the atmosphere. Negative emissions technologies include large-scale afforestation and reforestation, bioenergy with carbon capture and storage (BECCS), biochar, enhanced natural weathering of silicates or carbonates, ocean-based methods such as alkalinity enhancement and fertilization, and direct air CO_2 capture and storage (DACCS). There are risks, uncertainties and costs associated with these negative emissions options, many of which: rely on technologies that are not yet widely commercialised; are likely to come with higher costs than many existing mitigation options; may exacerbate biodiversity loss and displace food production where they require land (afforestation, reforestation and BECCS); or come with risks of impermanence (afforestation and reforestation).

The negative emissions challenge is often falsely assumed to arise only when overshoot is envisaged or only at the point at which net global carbon emissions turn negative. Negative emissions will be required in practically all 1.5°C pathways - even without overshoot. 1.5°C scenarios generally involve some gross positive emissions being offset by some gross negative emissions so some contribution of negative emissions technologies is required in the years before emissions reach net zero. Advancing policy initiatives to commercialise a range of negative emissions technologies that deliver permanent removal of CO_2 seems to be of utmost importance in all feasible net-zero worlds, and rapid progress in their deployment is required.

However, a budget premised on overshooting 1.5°C is certain to rely on negative emissions to a greater extent than a 1.5°C budget without overshoot, and the extra challenges this presents should be taken into account. In this report, the cumulative emissions budget is only provided up to the point of peak warming. In order to achieve warming of below 1.5°C by the end of the century following a 1.6°C peak, additional net negative emissions have to be brought about by permanent carbon dioxide removal (CDR) options of some sort. In that context, additional equity considerations arise[30].

[30] See e.g., Kaylin Lee et al 2021 Environ. Res. Lett. 16 094001, dx.doi.org//10.1088/1748-9326/ac1970 or Fyson, C.L., Baur, S., Gidden, M. et al. Fair-share carbon dioxide removal increases major emitter responsibility. Nat. Clim. Chang. 10, 836–841 (2020). https://doi.org/10.1038/s41558-020-0857-2

4 Derivation of global emissions budgets in line with the IPCC AR6

This section outlines the approach to deriving global emissions budgets based on up-to-date science as assessed in the IPCC AR6 report, adjusted as required to produce budgets aligned to the emissions scope and timeframes defined in Victoria's *Climate Change Act 2017*.

The following steps to derive the required global emissions budget are described:

- Step 1: The remaining carbon budget from 2013 onwards;
- Step 2: The remaining carbon budget up to 2050;
- Step 3a: Turning the carbon budget into an emissions budget;
- Step 3b: Accounting for different LULUCF accounting methods; and
- Step 3c: Accounting for international aviation and shipping.

4.1 Step 1: The remaining carbon budget from 2013 onwards

The IPCC AR6 WG1 report provides updated remaining global carbon budgets from the beginning of 2020 for temperature rise relative to 1850-1900 (Table SPM.2, and Table 5.8).

The Victorian emission budgets derived for the Combet Panel were based on the IPCC Special Report on 1.5°C warming (SR1.5), published in 2018. Developments incorporated in the IPCC AR6 WG1 resulted in larger emissions budgets for the same temperature and probability than were included in SR1.5, largely because:

- The treatment of Earth System feedbacks not represented in Earth System models was revised to be more in line with wider literature and understanding of these processes (although they still come with a very large uncertainty);
- The estimate of historical warming for the relevant period went down slightly (approximately 0.03°C, noting that the estimate of historical warming is also accompanied by a relatively large uncertainty); and
- The uncertainty in the sensitivity of the climate system to CO_2 emissions was reduced, which leads to larger budgets for a 67% chance of keeping warming below a certain limit.

Note that subsequent analysis by the IPCC AR6 WG3 highlights the uncertainties associated with non-CO_2 mitigation. For example, there is a wide range of options for non-CO_2 mitigation, including high methane and N_2O reductions via dietary changes. When considering the range from the WG3 analysis, the WG1 budgets are at the large end of the uncertainty range.

The Independent Expert Panel advising on a 2035 target for Victoria requested that two global budgets be used as a starting point for estimating emissions budgets for Victoria – one consistent with 1.5°C without overshoot, and one consistent with 1.5°C with slight overshoot, noting that the latter could also be considered to be a "well-below 2°C" budget.

To provide these budgets, we took the IPCC AR6 WG1 assessment of the remaining global carbon budgets from 2020 for 50% probability of limiting warming to 1.5°C and 1.6°C respectively. We use the WG1 budgets to be consistent with the overall approach taken in

AR6 (where carbon budgets are reported in WG1). As discussed above (3.2 and Table 1), the 1.6°C with 50% probability budget can be considered to be an appropriate proxy for a 1.5°C with limited overshoot budget or alternatively a "well-below 2°C" budget. There is no international consensus on the definition of a well-below 2°C temperature target, and different analyses, in different jurisdictions and studies, have approached the question in different ways and come to different conclusions as a result (see Appendix 2).

The budgets for 50% probability of limiting warming to 1.5°C and 1.6°C are shown in Table 2, with the required adjustments for:

- **The timeframe of relevance for the derivation of the Australian and Victorian emissions budgets**: The starting point of the emission budget consideration is 2013, consistent with the Climate Change Authority (2014) and Combet Panel (2019). The 2013 start date is held fixed in the past, rather than being updated to 2020 or a later year, because the underlying philosophy of a carbon budget is that if a state uses more (or less) of its budget in the early years, the state would have less (or more) emissions available in the later years. Updating all calculations to the recent past would negate that effect and reward high early emissions, and vice versa, punish early reductions in emissions.
- **Earth system feedbacks:** Unlike in the respective central numbers of IPCC SR1.5°C, the earth system feedbacks such as permafrost are included in the IPCC ARG WG1 remaining carbon budget. We include this step in our below description of the calculations for consistency with past approaches for deriving carbon budgets for Victoria, and to clarify that zero adjustments to the IPCC AR6 WG1 budget are required because the feedbacks are already included.
- **Pre-industrial warming:** The IPCC AR6 WG1 remaining carbon budget numbers are provided relative to the 1850-1900 base year, rather than from pre-industrial times, which is what is required for consistency with the Paris Agreement goal. This is partly because earth system models commence their simulations in 1850 due to computational constraints and partly because early instrumental temperature observations started around 1850. Pre-industrial temperatures are around -0.1°C (range +0.1 to -0.3°C) cooler than the 1850-1900 period, according to the IPCC AR6 WG1 report estimates from proxy temperature records[31]. This 0.1°C adjustment is applied (consistent with the approach adopted by the Combet Panel) by subtracting 150 $GtCO_2$ from the IPCC reported budgets (which apply for warming relative to 1850-1900). We use 150 $GtCO_2$ because it is the difference in remaining carbon budget for 1.5°C and 1.6°C reported in AR6 WG1.

[31] See Cross-Chapter Box 1.2 in Chapter 1 of IPCC AR6 WG1 report, available at https://www.ipcc.ch/report/ar6/wg1/.

Table 2 – Step 1: Global remaining carbon from 2013

Temperature level and likelihood of staying below	The remaining global carbon budget from Jan 2020 onwards listed in IPCC AR6 WG1 Table 5.8 for warming relative to 1850-1900	Adjustments so the starting year is 2013 (to account for global emissions from 2013 to 2020)	Earth – system feedbacks*	Reduction so warming targets are relative to pre-industrial levels not relative to 1850-1900 (0.1°C adjustment)	The remaining global carbon budget from Jan 2013 onwards for warming relative to pre-industrial levels
<1.6°C @ 50%	650 $GtCO_2$	+ 277 $GtCO_2$	- 0 $GtCO_2$	- 150 $GtCO_2$	= 777 $GtCO_2$
<1.5°C @ 50%	500 $GtCO_2$	+ 277 $GtCO_2$	- 0 $GtCO_2$	- 150 $GtCO_2$	= 627 $GtCO_2$

**No adjustments necessary. The IPCC AR6 WG1 remaining carbon budget already includes permafrost and other biogeochemical feedbacks.

4.2 Step 2: The remaining carbon budget up to 2050

The time frame for the emissions budget for Victoria is 2013 to 2050. The 2013 start is determined by the starting year for previous Australian and Victorian budgets. The 2050 end point is determined by the Climate Change Act 2017 which requires Victoria to reach net zero GHG emissions by 2050.[32] To assess if the remaining carbon budget calculated in Step 1 needs to be adjusted to derive a carbon budget to 2050, we consider whether relevant mitigation pathways include positive or net negative emissions after 2050.

The considered mitigation pathways in this report are taken from the IPCC AR6 Working Group 3 (WG3) report, published in 2022[33]. In the lowest warming category of IPCC WG3 scenarios (the "C1" category), peak median warming is up to 1.6°C and median end of century warming is below 1.5°C. For C1 scenarios, net zero CO_2 emissions are typically reached around 2050 and cumulative CO_2 emissions from 2020 peak at 510 $GtCO_2$ in the median, with a 5-95% range of 330 – 710 $GtCO_2$ (where this range is largely driven by different levels of methane and other non-CO_2 GHG mitigation).

The IPCC AR6 WG1 1.6°C with 50% chance budgets are used as a proxy for the upper end of the mitigation scenarios that deliver the lowest peak warming (referred to as the C1 category in IPCC AR6 WG3). This C1 category of scenarios has peak warming from 1.4°C (a few scenarios peak below 1.5°C) to 1.6°C and is not well represented by a single peak temperature number. This scenario class implies a slight reduction of global-mean temperatures in the second half of the century, driven by net negative CO_2 emissions and/or non-CO_2 emissions reductions. As a result, these 1.6°C with 50% chance budgets are a suitable proxy for the upper limit of a 1.5°C with small overshoot scenario and allow a direct connection with the socioeconomic modelling insights from IPCC WG3. These pathways

[32] We note that the Victorian Government has committed to legislate an earlier net zero emissions date of 2045. At the time of writing of this report, this has not yet been implemented. While our analysis uses a net zero date of 2050, this difference does not affect any presented results on the remaining carbon budget. An earlier net-zero year for Victoria will not imply a smaller or larger carbon budget up to the point of net-zero emissions, although it will change whether Victoria is consistent with those budgets or not.

[33] https://www.ipcc.ch/report/ar6/wg3/

generally reach net zero by 2050, so no adjustment that accounts for post-2050 positive emissions is required to turn the remaining carbon budget from 2013 into a budget for 2013-2050 (the relevant time period for Victoria given its net zero goal). We provide this step here for complete clarity when comparing to the analysis used by the Combet panel.

Table 3 – Step 2: Turning the remaining carbon budget until net zero into one up to 2050

Temperature level and likelihood of staying below	The remaining global carbon budget from Jan 2013 onwards for warming relative to pre-industrial levels (Table 2)	Given the 1.5°C scenarios in IPCC AR6 WG3, it is reasonable to assume net zero is reached around 2050. No adjustment is required to turn carbon budgets until net zero into carbon budgets to 2050	The remaining global carbon budget from Jan 2013 until 2050 for warming relative to pre-industrial levels
<1.6°C @ 50%	777 $GtCO_2$	+ 0 $GtCO_2$	= 777 $GtCO_2$
<1.5°C @ 50%	627 $GtCO_2$	+ 0 $GtCO_2$	= 627 $GtCO_2$

4.3 Step 3a: Turning the carbon budget into a GHG emissions budget

To derive GHG emission reduction targets from remaining carbon budgets, it is necessary to translate the carbon budgets into GHG emissions budgets. The concept of remaining budgets is, strictly speaking, only valid for CO_2 because every CO_2 emission causes the same near-permanent increase in global-mean temperatures. However, the translation into a GHG emission budget is a pragmatic and valid choice for well-defined time-horizons, like the 30 years between now and 2050 considered here because of the strong correlation between cumulative CO_2 emissions and cumulative GHG emissions in cost-effective mitigation scenarios.

The very strong correlation between cumulative CO_2 emissions and cumulative GHG emissions is evident from analysing the complete IPCC AR6 WG3 database of mitigation and reference scenarios (as e.g., done in Chapter 1 of the IPCC AR6 WG1 report). We derive the regression using the AR5 GWP-100 metric because this is also used for Australia and Victoria's emissions reporting, yielding a regression function that cumulative GHG emissions between 2013 and 2050 (shown on the y-axis of Figure 2) are 1.21 times the cumulative CO_2 emissions between 2013 and 2050 (shown on the x-axis) with an offset of 235.37 Gt CO_2eq (**Figure 2**).

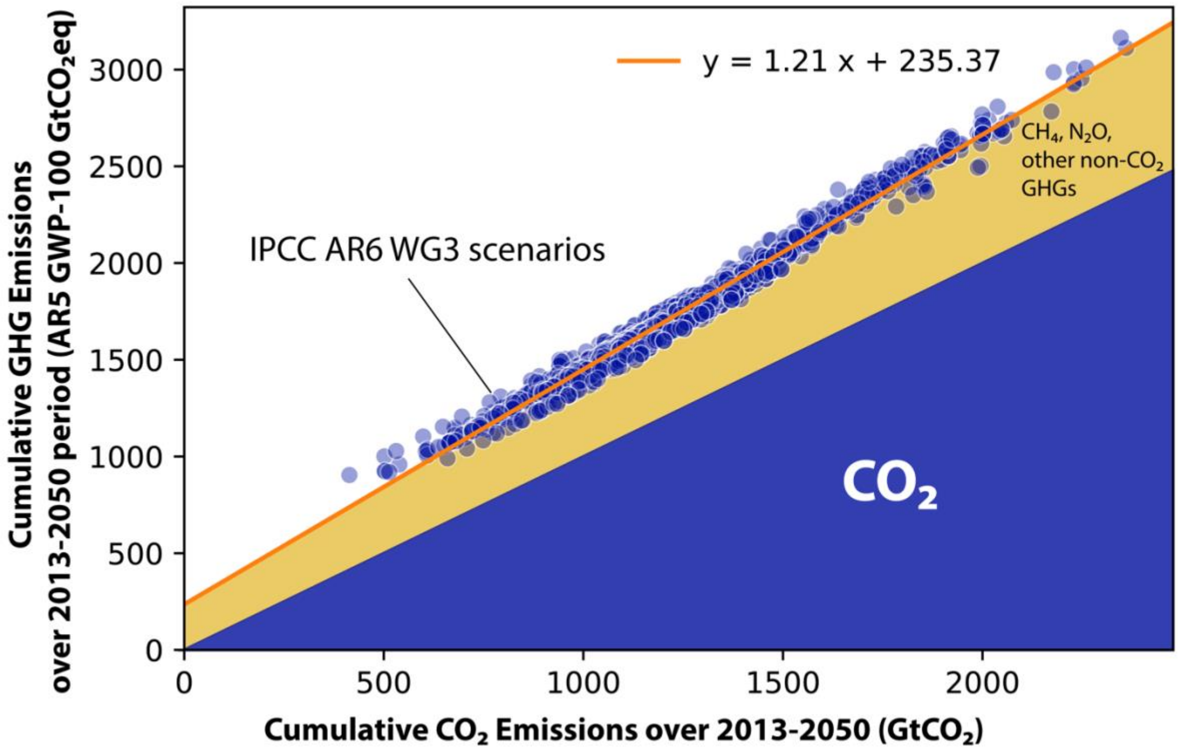

Figure 2 - The relationship between cumulative CO_2 emissions and cumulative GHG emissions between 2013 and 2050 within the IPCC AR6 WG3 database of emission scenarios.

Table 4 – Step 3a: Turning the global carbon budget into a GHG emission budget

Temperature level and likelihood of staying below	The remaining global carbon budget from Jan 2013 until 2050 for warming relative to pre-industrial levels (Table 3)	Additional **non-CO_2** GHG emissions when converting from a carbon budget to an emissions budget, derived on the basis of the AR6 WG3 scenarios	The remaining global emissions budget from Jan 2013 until 2050 for warming relative to pre-industrial levels
<1.6°C @ 50%	777 $GtCO_2$	+ 402 $GtCO_2eq$	= 1179 $GtCO_2eq$
<1.5°C @ 50%	627 $GtCO_2$	+ 370 $GtCO_2eq$	= 997 $GtCO_2eq$

4.4 Step 3b: Accounting for different LULUCF accounting methods

An emergent scientific realisation is that IPCC Guidelines for national inventory accounting for the land-use, land-use change and forestry (LULUCF) sector allow countries to include CO_2 fertilisation and other effects related to terrestrial carbon sinks in their reported LULUCF emissions. However, these sinks are not directly anthropogenically induced carbon sinks. The CO_2 fertilization effect is a response by the global carbon cycle - a response to the elevated atmospheric CO_2 concentration arising from our anthropogenic emissions. Accounting for the sinks due to CO_2 fertilisation strongly lowers the net-emission estimates from the land-use sector, even to the point that reported global land-use related emissions are close to zero or even slightly negative[34]. The directly induced anthropogenic land use emissions are however strongly positive (see e.g., range of estimates depicted in Figure 5.5 in Chapter 5 of the IPCC AR6 WG1 report).

We account for that difference in LULUCF accounting methods by reducing the CO_2 component of the remaining emissions budget by 15%, in line with the estimates provided by Grassi et al.[35] This adjustment is a new scientific finding and was only recently quantified. It represents an additional methodological step in comparison to the advice that was previously provided to the Combet Panel. Note that the underlying calculation only reduces the carbon part of the emission budget by 15%, which means that the total emission budget is reduced by less than 15%.

Table 5 – Step 3b: Accounting for the fact that IPCC methodologies for LULUCF include natural sinks

Temperature level and likelihood of staying below	The remaining global emissions budget from Jan 2013 until 2050 for warming relative to pre-industrial levels (Table 4)	15% adjustment to the carbon part of the emission budget to account for different **CO_2** sink accounting in IPCC methodology for national inventories and IPCC methodology for carbon budgets	The remaining global emissions budget from Jan 2013 until 2050 for warming relative to pre-industrial levels after LULUCF adjustment
<1.6°C @ 50%	1179 $GtCO_2eq$	- 117 $GtCO_2$	= 1063 $GtCO_2eq$
<1.5°C @ 50%	997 $GtCO_2eq$	- 94 $GtCO_2$	= 903 $GtCO_2eq$

[34] See e.g. discussion in Addendum 3 to the 2021 UNFCCC NDC Synthesis Report, paragraph 62 (available at: https://unfccc.int/sites/default/files/resource/cma2021_08_a03.pdf)

[35] See the Supplementary Figure 8 in Grassi, G., Stehfest, E., Rogelj, J., van Vuuren, D., Cescatti, A., House, J., Nabuurs, G.-J., Rossi, S., Alkama, R., Viñas, R. A., Calvin, K., Ceccherini, G., Federici, S., Fujimori, S., Gusti, M., Hasegawa, T., Havlik, P., Humpenöder, F., Korosuo, A., . . . Popp, A. (2021). Critical adjustment of land mitigation pathways for assessing countries' climate progress. *Nature Climate Change*, *11*(5), 425-434. https://doi.org/10.1038/s41558-021-01033-6

4.5 Step 3c: Accounting for international aviation and shipping

Before deriving country shares of emissions budgets, international aviation and shipping emissions must firstly be removed (in line with CCA, 2014[36]). We do this based on cumulative international aviation and shipping GHG emissions between 2013 and 2050 from the SSP1-1.9 and SSP1-2.6 mitigation scenarios.

Table 6 – Step 3c: Accounting for international aviation and shipping

Temperature level and likelihood of staying below	The remaining global emissions budget from Jan 2013 until 2050 for warming relative to pre-industrial levels after LULUCF adjustment (Table 5)	Removal of international aviation and shipping emissions	The remaining global emissions budget from Jan 2013 until 2050 for warming relative to pre-industrial levels after LULUCF adjustment and international aviation and shipping is removed
<1.6°C @ 50%	1063 $GtCO_2eq$	- 50 $GtCO_2$	= 1013 $GtCO_2eq$
<1.5°C @ 50%	903 $GtCO_2eq$	- 50 $GtCO_2$	= 853 $GtCO_2eq$

[36] https://www.climatechangeauthority.gov.au/sites/default/files/2020-06/Target-Progress-Review/Targets%20and%20Progress%20Review%20Final%20Report.pdf

5 Deriving the Australian emission budget

Australia's fair share is one of the core assumptions in deriving the Australian emissions budget. Since the Climate Change Authority's Targets and Progress Review (2014)[37], many analyses have used 0.97% as Australia's fair share of any global emissions budget, consistent with the approach taken in that review. The 0.97% share used by the CCA (2014) was derived on the basis of an approach known as modified contraction and convergence, first developed as part of the Garnaut Review in 2008. The 0.97% share was also adopted by the Combet Panel in 2019.

Other approaches to determining Australia's fair share produce a wide range of results. In our earlier analysis for the Combet Panel, we outlined five different fairness approaches (Table 7) and quantified their effects on Australia's "fair" share under both a 2°C and 1.5°C scenario. For a 1.5°C budget, resulting estimates range from 0.59% to 1.27%[38].

There is no internationally recognized approach to determine a fair share for Australia. However, adopting a "fair share" for Australia of 0.97% stands in contrast to approaches recently adopted by Germany, Ireland, and Denmark, which emphasise a share based on population. The German Advisory Council on the Environment ("Sachverständigenrat für Umweltfragen (SRU)")[39] proposed, and the German High Court adopted, a "fair share" for Germany and the EU28 that reflected their shares of the global population in a landmark decision that forced the previous German government to amend its climate policy targets[40]. In the Australian context, using population share would imply a fair share of 0.33% rather than 0.97%[41]. This raises the question, to what extent is the 0.97% share of remaining emissions considered a fair share not only by Australia but also by other countries?

In Table 8 we calculate the emissions budgets for Australia based on a fair share of:

- 0.97% - which reflects the modified contraction and convergence approach used by the Garnaut Review (2008), The Climate Change Authority (2014), and the Combet Panel (2019), and
- 0.33% - which reflects an equal per capita approach. This results in negative emissions budgets for Australia from 2020-2050. Alternatively stated, if Australia's

[37] https://www.climatechangeauthority.gov.au/sites/default/files/2020-06/Target-Progress-Review/Targets%20and%20Progress%20Review%20Final%20Report.pdf

[38] Meinshausen, Robiou du Pont and Talberg (2018) "Greenhouse gas emission budgets for Victoria", available at: https://www.climatechange.vic.gov.au/__data/assets/pdf_file/0016/421702/Greenhouse-Gas-Emissions-Budgets-for-Victoria.pdf

[39] Available at: https://www.umweltrat.de/SharedDocs/Downloads/EN/01_Environmental_Reports/2020_08_environmental_report_chapter_02.html

[40] https://www.bundesverfassungsgericht.de/SharedDocs/Entscheidungen/DE/2021/03/rs20210324_1bvr265618.html

[41] Following the 2019 population data from the UN World Population Prospects 2019, available at: https://population.un.org/wpp/

fair share is taken to be 0.33% of the global emissions budget, it used the entire emissions budget for both 1.5°C @ 50% and 1.6°C @ 50% between 2013 and 2019.

Table 7 – Allocation approaches investigated, based on Robiou du Pont (2017) and IPCC AR5 categories[42]

Allocation type	Corresponding AR5 IPCC Category	Description
Equal per capita	Equality	For all nations, annual emissions per person converge towards an equal value in 2040 (or other date).
Equal cumulative per capita	Equal cumulative per capita	Each nation has the same ratio of cumulative emissions to population over the 1990-2050 period. As a result, nations with high historical per capita emissions have lower future emissions allocations.
Capability	Capability	Allocation is based on nations' abilities to pay for emissions reductions. Nations with higher GDP per capita have lower emissions allocations.
Greenhouse Development Rights	Responsibility-capability-need	This approach preserves a "right to development" through the allocation of required emissions reductions.
Constant emissions ratio	Staged approaches	Maintains current emissions ratios (preserves status-quo in emissions allocations). This approach, often referred to as "grandfathering", is generally not considered an equitable option and is not supported as such by any country for dividing a global budget between nations.

Table 8 –Deriving the Australian emission budget

Temperature level and likelihood of staying below	Australian share of global emissions budget from 2013 until 2050 based on a) CCA, 2014 and b) equal per capita shares	The remaining global emissions budget from Jan 2013 until 2050 for warming relative to pre-industrial levels after LULUCF adjustment and international aviation and shipping is removed (Table 6)	The remaining Australian emissions budget from Jan 2013 until 2050 for warming relative to pre-industrial levels
<1.6°C @ 50%	**(a) 0.97%**	x 1013 $GtCO_2eq$	= 9.83 $GtCO_2eq$
<1.5°C @ 50%	**(a) 0.97%**	x 853 $GtCO_2eq$	= 8.27 $GtCO_2eq$
<1.6°C @ 50%	**(b) 0.33%**	x 1013 $GtCO_2eq$	= 3.34 $GtCO_2eq$
<1.5°C @ 50%	**(b) 0.33%**	x 853 $GtCO_2eq$	= 2.81 $GtCO_2eq$

[42] Table is a modified version of Table 2 in Meinshausen, Robiou du Pont and Talberg (2018) "Greenhouse gas emission budgets for Victoria", available at: https://www.climatechange.vic.gov.au/__data/assets/pdf_file/0016/421702/Greenhouse-Gas-Emissions-Budgets-for-Victoria.pdf

6 Deriving the Victorian emission budget

Dividing an Australian emission budget into budgets for each state and territory also requires value judgements about fair shares. It should be noted that fairness principles are applied in a different context when they are applied sub-nationally compared to when they are applied internationally. In a national context, the question of fairness can be, to a large degree, dealt with by the federal budget, the tax revenue stream and re-allocation of public spending.

The previous advice to the Combet panel presented calculations for a range of fairness options[43]. The respective resulting emission shares are provided in Table 9. On top of these shares, we have also added shares based on an equal per capita emissions approach.

Table 9 – Fairness approaches to split up cumulative 2017-2050 emissions from Australian states and territories (share (%)[44]

Approach	ACT	NSW	NT	QLD	SA	TAS	VIC	WA	Total
Contraction & convergence - 2030 convergence	1.2	28.1	1.8	24.1	5.9	1.1	23.7	14.1	100
Contraction & convergence - 2050 convergence	0.8	26.1	2.5	26.8	5.3	0.5	22.7	15.4	100
Capability (GDP per capita)	0.7	25.0	2.4	27.8	5.2	0.4	23.4	15.1	100
Grandfathering	0.3	25.1	3.1	29.0	5.0	0.0	21.7	15.7	100
Responsibility (equal cumulative per capita)	4.3	36.8	-1.4	7.8	9.0	0.6	31.1	11.7	100
Equal per capita*	1.8	31.4	1.0	20.5	7.0	2.2	25.5	10.7	100

*Based on population shares of Australian States and Territories in 2022 (ABS, March 2022)

The Independent Expert Panel advising on a target for 2035 decided to use estimate Victoria's share of an Australian budget using methods that correspond to the methods used to estimate Australia's share of a global budget. Specifically, when (modified) contraction and convergence is used, Australia's share of the global budget is 0.97% and Victoria's share of the Australian budget is 22.7%. When equal per capita is used, Australia's share of the global budget is 0.33% and Victoria's share of the Australian budget is 25.5%.

This yields four emissions budgets for Victoria (Table 10). If the starting point is an Australian emissions budget based on equal per capita shares, Victoria's remaining emissions budget from 2021 onwards is negative. In other words, under the assumption that budgets are divided based on equal per capita shares, Victoria's emissions budget for 1.5°C and 1.6°C with a 50% chance has already been exceeded.

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[43] Issues relevant to dividing an Australian emissions budget across states and territories are discussed in more detail in Part II of the previous advice to the Combet Panel, see Meinshausen, Robiou du Pont and Talberg (2018) "Greenhouse gas emission budgets for Victoria", available at: https://www.climatechange.vic.gov.au/__data/assets/pdf_file/0016/421702/Greenhouse-Gas-Emissions-Budgets-for-Victoria.pdf

[44] Modified from Table 5 in the previous advice to the Combet panel, see Meinshausen, Robiou du Pont and Talberg (2018) "Greenhouse gas emission budgets for Victoria", available at: https://www.climatechange.vic.gov.au/__data/assets/pdf_file/0016/421702/Greenhouse-Gas-Emissions-Budgets-for-Victoria.pdf

Table 10 –Deriving the Victorian emission budget

Temperature level and likelihood of staying below	**Australian share of global emissions budget from 2013 until 2050 based on a) CCA, 2014 and b) equal per capita shares**	**Victorian share of the Australian emissions budget from 2017 to 2050 based on c) contraction and convergence d) equal per capita allocations (Table 9)**	The remaining Australian emissions budget from Jan 2013 until 2050 for warming relative to pre-industrial levels (Table 8)	Australian GHG emissions over 2013-2016 (AR5 GWP-100)	Victorian GHG emissions over 2017-2020 (AR5 GWP100)	**The remaining Victorian emissions budget from Jan 2021 until 2050 for warming relative to pre-industrial levels**
<1.6°C @ 50%	**(a) 0.97%**	**(c) 22.7% x**	(9.83 $GtCO_2eq$	- 2.18 $GtCO_2eq$)	-0.37 $GtCO_2eq$	= 1.37 $GtCO_2eq$
<1.5°C @ 50%	**(a) 0.97%**	**(c) 22.7% x**	(8.27 $GtCO_2eq$	- 2.18 $GtCO_2eq$)	-0.37 $GtCO_2eq$	= 1.02 $GtCO_2eq$
<1.6°C @ 50%	**(b) 0.33%**	**(d) 25.5% x**	(3.34 $GtCO_2eq$	- 2.18 $GtCO_2eq$)	-0.37 $GtCO_2eq$	= -0.071 $GtCO_2eq$
<1.5°C @ 50%	**(b) 0.33%**	**(d) 25.5% x**	(2.81 $GtCO_2eq$	- 2.18 $GtCO_2eq$)	-0.37 $GtCO_2eq$	= -0.205 $GtCO_2eq$

Appendix 1: Remaining carbon budget table from IPCC WG1 AR6

Table 5.8 on remaining carbon budges from Chapter 5 of the IPCC WG1 AR6 report.

Table 5.8: The assessed remaining carbon budget and corresponding uncertainties. Assessed estimates are provided for additional human-induced warming expressed as global average surface air temperature since the recent past (2010–2019), which *likely* amounted to 0.8 to 1.3 with a best estimate of 1.07°C relative to 1850–1900 (Table 3.1 in Chapter 3).

Additional warming since 2010–2019 *(1)	Warming since 1850–1900 *(1)	Remaining carbon budget*(2) starting from 1 January 2020 and subject to variations and uncertainties quantified in the columns on the right					Scenario variation	Geophysical uncertainties			
°C	°C	Percentiles of TCRE*(3)*(4) *PgC ($GtCO_2$)*					Non-CO_2 scenario variation *(5)	Non-CO_2 forcing and response uncertainty *(6)	Historical temperature uncertainty *(1)	ZEC uncertainty *(7)	Recent emissions uncertainty*(8)
		17th	*33rd*	*50th*	*67th*	*83rd*	*PgC ($GtCO_2$)*	*PgC ($GtCO_2$)*	*PgC ($GtCO_2$)*	*PgC ($GtCO_2$)*	*PgC ($GtCO_2$)*
0.23	1.3	*100 (400)*	*60 (250)*	*40 (150)*	*30 (100)*	*10 (50)*	Values can vary by at least ±60 PgC (±220 $GtCO_2$) due to choices related to non-CO_2 emissions mitigation	Values can vary by at least ±60 PgC (±220 $GtCO_2$) due to uncertainty in the warming reponse to future non-CO_2 emissions	±150 PgC (±550 $GtCO_2$)	±115 PgC (±420 $GtCO_2$)	±6 PgC (±20 $GtCO_2$)
0.33	1.4	*180 (650)*	*120 (450)*	*90 (350)*	*70 (250)*	*50 (200)*					
0.43	1.5	*250 (900)*	*180 (650)*	*140 (500)*	*110 (400)*	*80 (300)*					
0.53	1.6	*330 (1200)*	*230 (850)*	*180 (650)*	*150 (550)*	*110 (400)*					
0.63	1.7	*400 (1450)*	*290 (1050)*	*230 (850)*	*190 (700)*	*150 (550)*					
0.73	1.8	*470 (1750)*	*350 (1250)*	*280 (1000)*	*230 (850)*	*180 (650)*					
0.83	1.9	*550 (2000)*	*400 (1450)*	*320 (1200)*	*270 (1000)*	*120 (800)*					
0.93	2	*620 (2300)*	*460 (1700)*	*370 (1350)*	*310 (1150)*	*250 (900)*					
1.03	2.1	*700 (2550)*	*510 (1900)*	*420 (1500)*	*560 (1250)*	*280 (1050)*					
1.13	2.2	*770 (2850)*	*570 (2100)*	*460 (1700)*	*390 (1400)*	*310 (1150)*					
1.23	2.3	*850 (3100)*	*630 (2300)*	*510 (1850)*	*430 (1550)*	*350 (1250)*					
1.33	2.4	*920 (3350)*	*680 (2500)*	*550 (2050)*	*470 (1700)*	*380 (1400)*					

*(1) Human-induced global surface air temperature increase between 1850–1900 and 2010–2019 is assessed at 0.8–1.3°C (*likely* range; Chapter 3) with a best estimate of 1.07°C. Warming here reflects GSAT, as TCRE and other estimates are GSAT based. Combined with a central estimate of TCRE (1.65 °C EgC^{-1}) the uncertainty in historical human-induced GSAT warming results in a potential variation of remaining carbon budgets of ±150 PgC or ±550 $GtCO_2$.

*(2) Historical CO_2 emissions between 1850 and 2019 have been estimated at about 655 ± 65 PgC (1-sigma range, or 2390 ± 240 $GtCO_2$, see Table 5.1). Note that 57 PgC (210 $GtCO_2$) have been emitted from the middle of the 2010-2019 reference period (2015) until the end of 2019 (Friedlingstein et al., 2020).

*(3) TCRE: transient climate response to cumulative emissions of carbon, assessed to fall *likely* between 1.0–2.3 °C EgC^{-1} with a normal distribution. PgC values are rounded to the nearest 10; $GtCO_2$ values to the nearest 50. For comparison, assuming a lognormal distribution with a 1.0–2.3 °C EgC^{-1} central 66% range instead of a normal distribution would increase remaining carbon budgets at the 17th, 33rd, 50th, 67th, and 83rd percentile with 3%, 10%, 12%, 9%, 2%, respectively. Future non-CO_2 contributions in these remaining carbon budget estimates are based on the scenarios assessed in the IPCC SR1.5 report and estimated as the median quantile regression of non-CO_2 warming since 2010–2019 relative to total additional warming since 2010–2019 at the time scenarios reach net-zero CO_2 emissions (Forster et al., 2018; Huppmann et al., 2018; Rogelj et al., 2018b).

*(4) Additional Earth system feedbacks are included in the remaining carbon budget estimates as discussed in Section 5.5.2.2.5. The tropospheric ozone and methane lifetime contributions are included through the non-CO_2 warming projections by the AR6-calibrated MAGICC emulator, while the remaining feedbacks are assessed totalling a combined feedback of magnitude 7 ± 27 PgC K^{-1} (1-sigma range, or 26 ± 97 $GtCO_2$ $°C^{-1}$).

*(5) Variations due to different scenario assumptions related to the future evolution of non-CO_2 emissions in mitigation scenarios reaching net zero CO_2 emissions (Huppmann et al., 2018; Rogelj et al., 2018b) of at least ±0.1°C (spread across scenarios). Combined with a central estimate of TCRE (1.65 °C EgC^{-1}) this results in at least ±60 PgC or ±220 $GtCO_2$. This spread reflects the variation in the underlying scenario ensemble but is not a formal likelihood. WGIII will reassess the potential for non-CO_2 mitigation based on literature since the SR1.5.

*(6) Remaining carbon budget variation due to geophysical uncertainty in forcing and temperature response of non-CO_2 emissions of the order of ±0.1°C, very largely range (5–95%) of non-CO_2 response (Section 5.5.2.2.3). Combined with a central estimate of TCRE (1.65 °C EgC^{-1}) this results in at least ±60 PgC or ±220 $GtCO_2$.

*(7) The variation due to the ZEC is estimated for a central TCRE value of 1.65 °C EgC^{-1} and a 1-sigma ZEC range of 0.19°C. In real-world pathways, the magnitude of this effect will depend on the pace of CO_2 emissions reductions to net zero.

*(8) Historical emissions uncertainty reflects the ±10% uncertainty in the historical emissions estimate since 1 January 2015.

Climate Resource

Appendix 2: Summary of approaches in other jurisdictions

Other jurisdictions that make use of budgets in guiding their emissions reductions commitments and policies adopt a range of approaches. Many of those that set five-yearly emissions reductions targets or carbon budgets, are informed to differing degrees by both:

- Global carbon budgets consistent with the Paris Agreement temperature goal (described as a top-down approach, or a "climate science carbon budget" in Figure A1); and
- The budgets assessed as delivering the emissions reductions targets in policy or legislation (e.g. net-zero by 2050) at a rate of reduction considered possible (a bottom up approach, or a "climate policy carbon budget" in Figure A1).

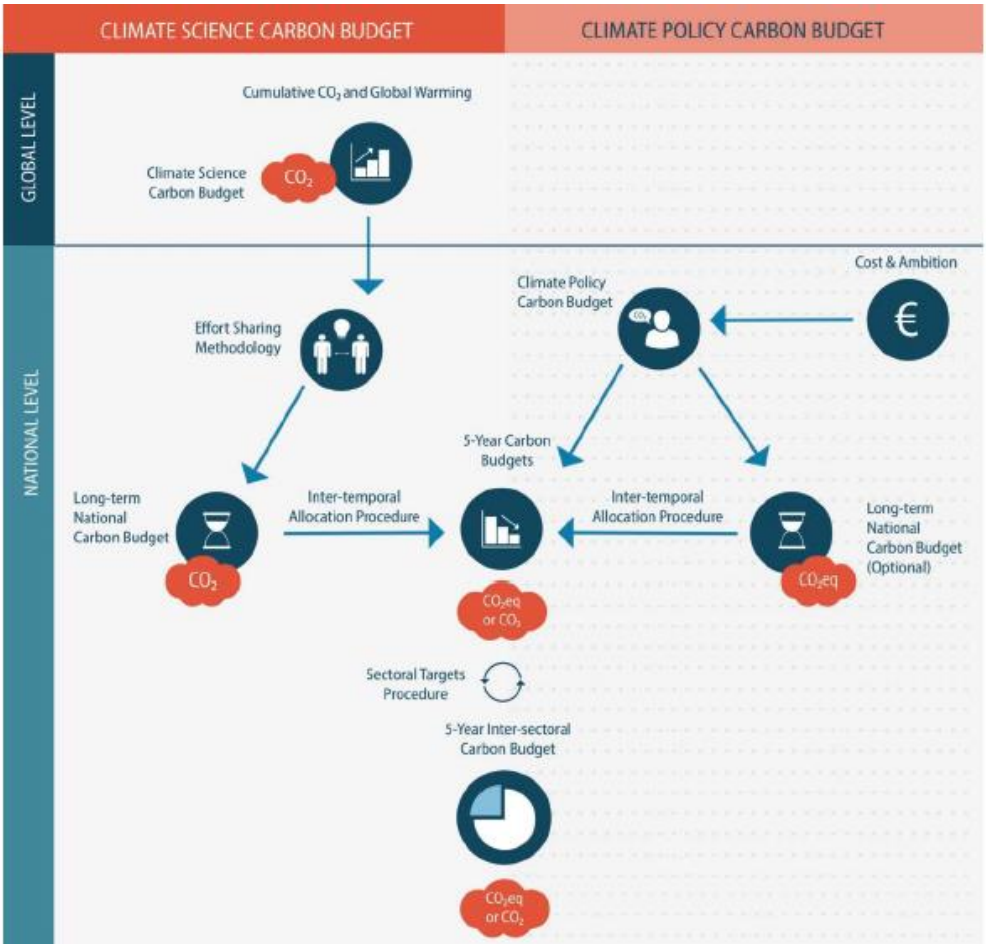

Figure A1 – two approaches to developing five-yearly carbon budgets. Source: McGuire et al,. Discussion Paper: The role of carbon budgets in translating the Paris Agreement into national climate policy, MaREI, Environmental Research Institute (ERI) at University College Cork[45].

In the case of the UK and Ireland, the bottom-up approach plays a strong role in guiding the 5-yearly carbon budgets recommended, and the resulting emissions are then checked to

[45] Available at: https://www.marei.ie/wp-content/uploads/2020/10/Discussion-Paper_The-role-of-carbon-budgets-in-translating-the-Paris-Agreement-into-national-climate-policy.pdf

ensure they are consistent with global pathways in line with different temperature outcomes and effort sharing approaches.

The UK does not specify a single temperature goal, probability, or effort sharing method for determining a share of a global carbon budget. The Sixth Carbon Budget produced by the UK Committee on Climate Change instead highlights the range in global and country-specific carbon budgets associated with limiting warming to a given temperature goal (due to the issues discussed in this report) and explores where the recommended path for the UK sits within this range. It notes that: the date for reaching net-zero emissions is earlier than that required for the world as a whole to keep warming to below 1.5°C with 50% probability, because the Committee believes that such early action is appropriate for a developed country such as the UK; under its proposed path, per capita emissions start at a level higher than the global average (because of historically high emissions), fall to a level consistent with the global average required to limit warming to 1.5°C in 2035 and are lower in subsequent years; and despite the strong reductions, between now and 2050, UK per capita cumulative emissions are higher than the global average consistent with 1.5°C, yet lower than "well-below" 2°C.[46]

French legislation incorporates 5-yearly carbon budgets, which are based on a bottom-up approach, and not explicitly assessed against a global carbon budget or emissions sharing approach to our knowledge.[47]

In Denmark, the legislated emissions reductions targets to 2030 and 2050 aim to be consistent with its share of a global carbon budget with 50%-67% probability of limiting warming to 1.5°C, using equal per capita emissions. A carbon budget approach is not used as a starting point for setting interim emissions reduction goals or policies, rather only as a hindsight check.[48]

The USA describes its updated 2030 NDC and 2050 net-zero goal as putting "the United States ahead of the trajectory required to keep 1.5°C within reach", but supporting analysis of the probability of achieving this temperature outcome, approach to effort sharing, or extent to which the trajectory relies on overshoot is not in the publicly available supporting documents to our knowledge.[49] Analysis by the Climate Action Tracker suggests this target is almost sufficient for a less than 2°C world based on the CAT's quantification of the USA's fair share. [50]

Examples of the approaches in different jurisdictions are summarised in Table A1.

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[46] The Committee on Climate Change, The Sixth Carbon Budget: The UK's path to Net-Zero, Ch. 7 & 8

[47] Ministère de la Transition Écologique, National low carbon strategy (SNBC), 2020, and McGuire et al., The role of carbon budgets in translating the Paris Agreement into national climate policy, Discussion Paper (undated)

[48] The Danish Council on Climate Change, A framework for Danish climate policy: Input for a new Danish climate act with global perspectives, October 2019, p 9-11.

[49] The United Department of State and the United States Executive Office of the President, The Long-Term Strategy of the United States - Pathways to Net-Zero Greenhouse Gas Emissions by 2050, November 2050.

[50] https://climateactiontracker.org/countries/usa/

Table A1 – Examples of approaches to calculating local emissions budgets in different jurisdictions

Jurisdiction	Broad approach and use of global carbon budget	Temperature goals and probabilities	Effort sharing	Overshoot
UK	Highest possible ambition, with consideration given to where this sits in the range implied by global emissions budgets consistent with the Paris Agreement goal and effort sharing approaches	The global carbon budget range uses pathways with at least a 66% probability of keeping peak warming below 2°C and a 50% probability of 1.5°C as upper and lower bounds[51]	Consistency with a range of effort sharing approaches is considered but no single approach is adopted (consistent with the focus on highest ambition as the starting point)	The lower bound of the range for global carbon budgets is based on pathways with no or low overshoot[52], although the UK CCC notes that it considers it "not prudent to plan for an intentional temporary overshoot"
France	5-yearly carbon budgets are not explicitly tied to a global carbon budget or effort sharing approach	Recent work on France's carbon footprint (domestic and imported emissions) asserts that the targets set are consistent with global pathways for 1.5°C, but no probability is discussed[53]	Not explicitly addressed in public material supporting policy to our knowledge	Overshoot not explicitly discussed
New Zealand	An obligation to set emissions budgets consistent with limiting temperature rise to 1.5°C is in legislation[54]	Interquartile range of SR1.5 pathways consistent with 50-66% chance of limiting warming to 1.5°C[55]	Consistency with a range of effort sharing approaches is considered, but no single approach is proposed by the NZ CCC[56]	Based on pathways from IPCC SR1.5 with no or limited overshoot[57]

[51] The Committee on Climate Change, The Sixth Carbon Budget: The UK's path to Net-Zero, p.19, p.325
[52] The Committee on Climate Change, The Sixth Carbon Budget: The UK's path to Net-Zero, Ch 7 & 8
[53] Haut Conseil pour le CLIMAT Tackling France's Carbon Footprint, October 2020
[54] Climate Change Response (Zero Carbon) Amendment Act 2019 (NZ)
https://www.legislation.govt.nz/act/public/2019/0061/latest/LMS183848.html#LMS183810
[55] NZ Climate Change Commission, Ināia tonu nei: a low emissions future for Aotearoa, May 2021, pp. 192-194.
[56] Ibid pp. 352-357
[57] Ibid Chapter 21, p. 354

Ireland	Top-down allocation of the global carbon budget provided context for five yearly carbon budgets that would deliver emissions reductions required in regulations/legislation for 2030 and 2050	50% probability of 1.5°C and 67% of staying below 2°C[58]	Population (equal per capita emissions) with some context specific adjustments	Overshoot not explicitly discussed. Land based negative emissions and methane reductions included as an adjustment to Ireland's share of the global carbon budget to 2050[59]
Denmark	Emissions reductions targets of a 70% reduction on 1990 levels by 2030 and net zero by 2050 set in legislation. The Danish CCC asserts these goals are consistent with its share of a global carbon budget. Carbon budgets not required to be used in setting interim 5-yearly targets[60]	50%-67% probability of 1.5°C[61]	Population (equal per capita emissions) adopted as the starting point, noting other effort sharing approaches would support a smaller budget for Denmark, or it contributing more to global mitigation efforts (including via climate finance)[62]	Overshoot not explicitly discussed
Scotland	Legislated requirement to set targets that do not exceed a fair and safe Scottish emissions budget to 2050.[63]	The UK CCC (the entity required to advise on a fair and safe emissions budget) did not detail the temperature goal or probability.[64] Targets of 75% on 1990 levels by 2030 and net zero by 2045 are reported as going beyond what the IPCC says is needed globally to	No single effort sharing method referenced, but clearly recognise the need to do better than the global average	Overshoot not explicitly discussed

58 Climate Change Advisory Council, Carbon Budget Technical Report, October 2021, p. 94
59 Carbon Budget Committee Outputs, Secretariat presentation to the Carbon Budget Committee, 28 June 2021
60 The Danish Council on Climate Change, A framework for Danish climate policy: Input for a new Danish climate act with global perspectives, October 2019, p. 10
61 Ibid, p. 10
62 Ibid, p. 11
63 Climate Change (Emissions Reduction Targets) (Scotland) Act 2019
64 The UK Committee on Climate Change letter of advice to the Cabinet Secretary for Environment, Climate Change and Land Reform, 2020

		prevent warming of more than 1.5°C.[65]		
Wales	5-yearly carbon budgets must be set to achieve the interim target and the 2050 net-zero target specified in legislation.[66] The budgets adopted are based on "highest possible ambition" [67], rather than starting from a top-down climate science budget approach.	The targets set are assessed to be in line with the Paris Agreement 1.5°C goal[68]	No single effort sharing method referenced, but the budget is assessed as delivering annual per capita emissions reductions before 2040 that are in line with global pathways consistent with the 1.5° goal[69]	Overshoot not explicitly discussed

[65] Scottish Government, Scotland's Contribution to the Paris Agreement - an indicative NDC. July 2021
[66] Welsh Government, Environment (Wales) Act 2016 fact sheet.
[67] UK Committee on Climate Change Advice Report: The path to a Net Zero Wales, December 2020, p.9
[68] Ibid, p.9
[69] Ibid, p.11

City level carbon budgets

Aside from nations and regions, there are also cities increasingly adopting an emission budget approach. One of the pragmatic approaches for cities to derive an emission budget is simply to spread out cumulative emissions under the assumption of a straight line approach to net-zero emissions[70].

As for national and regional targets, city emission budgets are often implicitly determined by setting a 100% phase out of net-emissions target and pursuing interim targets towards then, such as in the case of San Francisco[71].

Legal judgements

The German Federal Constitutional Court ruled in 2021 that the Federal Climate Change Act was partially unconstitutional because the annual emissions allowed until 2030 gave insufficient regard to what is required in subsequent decades to limit warming to well below 2°C or 1.5°C. The ruling set out a clear view on the derivation of a Paris-aligned budget for Germany[72]. The Court started from a global carbon budget consistent with a 67% probability of remaining well-below 2°C, which equated to around a 33% probability of limiting temperature to rise to 1.5°C.

[70] See e.g. https://100percentrenewables.com.au/wp-content/uploads/2019/10/100-RE-Setting-targets-for-community-emissions-Whitepaper.pdf

[71] https://sfenvironment.org/sites/default/files/fliers/files/sfe_focus_2030_report_july2019.pdf

[72] Available at: https://www.umweltrat.de/SharedDocs/Downloads/EN/01_Environmental_Reports/2020_08_environmental_report_chapter_02.html