Deriving a global 2013-2050 emission budget to stay below 1.5°C based on the IPCC Special Report on 1.5°C

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Summary

This paper provides advice to the Victorian interim targets Independent Expert Panel on developing a 1.5°C greenhouse gas emissions budget for Victoria for the period 2017-2050. It builds on decisions taken by the Independent Expert Panel based on advice provided to the Panel by Meinshausen, Robiou du Pont and Talberg in May 2018 on developing a 2°C emissions budget for Victoria for the period to 2050.

The IPCC Special Report on 1.5°C provides the latest scientific assessment on scenarios and information on 1.5°C carbon budgets. This new information is here used to derive a global emission budget that can be useful for the deduction of Australian and Victorian state level emission budgets.

This 2013-2050[1] global emission budget to stay below 1.5°C is **800 $GtCO_2$ eq**, including all major greenhouse gases (using a GWP-100 AR4 metric). This is derived from the central IPCC Special Report on 1.5°C result that to keep warming below 1.5°C with a 50% chance, cumulative carbon emissions have to be kept below 580 $GtCO_2$ from January 2018 onwards.

When using value judgements regarding Australia's and Victoria's respective fair shares of the global emissions budget and subtracting historical Australian and Victorian emissions for the period 2014-2016, this global emission budget can be turned into a remaining emissions budget for Victoria of **1.25 $GtCO_2$eq between 2017 and 2050**. The below briefing details the steps taken to derive the global 800 $GtCO_2$eq emission budget and the Victorian shares from the 580 $GtCO_2$ number in the IPCC Special Report on 1.5°C.

In the following, this briefing paper details the adjustment steps to derive a 1.5°C carbon budget for the Victorian context, starting from the recent IPCC Special Report on 1.5°C. In a first step, the global carbon budget is derived, in a second step the carbon budget is translated into one until 2050 and in the third step, the carbon budget is translated into an emission budget. The Australian and Victorian emissions budgets are then calculated as shares of the global budget and updated to the period 2017-2050 by subtracting historical emissions (see steps 4 and 5).

Step 1: A global 1.5°C carbon budget is ~500 $GtCO_2$

The IPCC report provides an estimate for a global remaining carbon budget of **580 $GtCO_2$** (excluding permafrost feedbacks) based on a 50% probability of limiting warming to 1.5 degrees relative to 1850 to 1900 during and beyond this century and a remaining carbon budget of 420 $GtCO_2$ for a 67% chance (see Table 2.2 in the IPCC Special Report on 1.5°C).

[1] The 2013-2050 time period is used to be consistent with the methodology previously used by the Panel.

There are a couple of steps to adjust that **580 $GtCO_2$** figure for the Australian discussion context. These steps are:

1) **2013 instead of 2018 starting year of remaining budget:** The Australian carbon budgets in the context of the national policy debate are often expressed with regard to a 2013 starting year, not 2018. Approximately 200 $GtCO_2$ of carbon emissions have been emitted over the years 2013 to 2017 globally, which have to be added to the IPCC Special Report 1.5°C number of 580 $GtCO_2$.
2) **Accounting for Earth System feedbacks, i.e. mainly permafrost**: The IPCC Special report provided a flat rate 100 $GtCO_2$ downward adjustment to account for permafrost feedbacks and other Earth System feedbacks that are not accounted for in the 580 $GtCO_2$ number. The IPCC provides an estimate related to feedbacks separately due to a different method to estimate those feedbacks that were still under-represented in the last generation of Earth System Models, namely permafrost. However, the scientific consensus and the IPCC's analysis leaves no doubt that they should be accounted for given those feedbacks eventuate sometime over the 21st century. Thus, unless net negative anthropogenic CO_2 emissions are relied upon for the second half of the century, the remaining carbon budget has to be reduced by 100 $GtCO_2$ to take into account that earth system feedbacks will lead to additional emissions of CO_2 and methane, which in turn amplify warming.
3) **Accounting for a 1.5°C warming above pre-industrial levels, not above 1850-1900 levels**. The Paris Agreement target of 1.5°C refers to warming relative to pre-industrial levels. Industrialisation and thereby the onset of substantial fossil-fuel related emissions started at the end of the 17th century, which is why 1750 is often used as the pre-industrial reference point. For temperatures, and also for the remaining carbon budget calculations, sometimes a proxy period is chosen, namely the 1850-1900 period. This both has to do with Earth System Models often being started only from 1850 and that instrumental temperature records go back to then. However, new studies put a closer estimate in relation to the pre-industrial (1720-1800) warming compared to the warming in the "early-industrial" period (1850-1900), roughly of the order of 0.1°C (Hawkins et al., 2017). Translating that 0.1°C change into a change of the remaining carbon budget amounts to another 180 $GtCO_2$ reduction of the 580 $GtCO_2$ number.

Those adjustments to the IPCC SR1.5 carbon budget can be shown in equation form as follows:

580 $GtCO_2$	**+200 $GtCO_2$**	**-100 $GtCO_2$**	**- 180 $GtCO_2$**	**= 500 $GtCO_2$**
The remaining carbon budget from Jan 2018 onwards listed in IPCC SR1.5 for a 50% warming to stay below 1.5°C warming relative to 1850-1900.	Enlarging the budget to account for global emissions from 2013 to 2018, so that the remaining budget's starting year is 2013	Reducing the remaining budget to account for permafrost-related feedbacks that are not represented in the 580 $GtCO_2$ number.	Reducing the remaining budget to account for a 1.5°C warming target relative to pre-industrial levels, not relative to early-industrial levels.	The remaining carbon budget from Jan 2013 onwards for a 50% warming to stay below 1.5°C warming relative to pre-industrial levels.

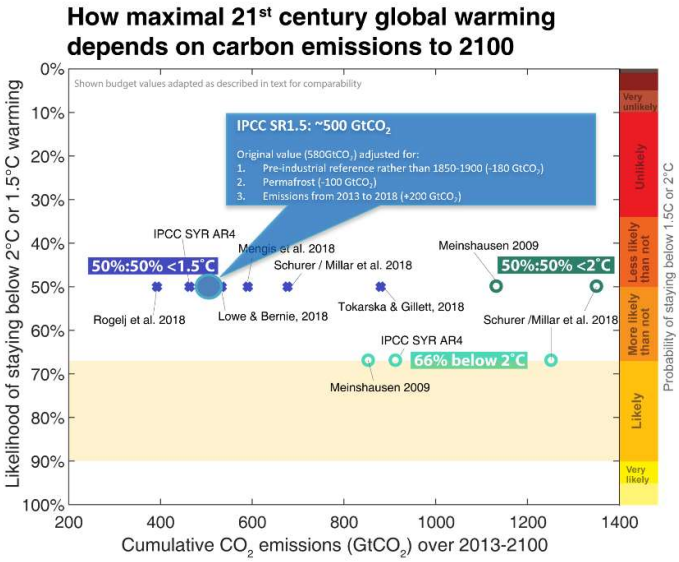

Figure 1 – Comparison of the adjusted IPCC SR1.5 carbon budget estimate with earlier estimates of a global 1.5°C (and a 2°C) budget.

In comparison to other studies (that vary in relation to their representation of feedbacks, reference levels, non-CO_2 forcings, climate sensitivity assumptions etc.), this adjusted IPCC SR1.5 is close to the headline number IPCC Synthesis report estimate of AR4, as shown in the Figure below.

Step 2: Turning a remaining carbon budget until 2100 into one until 2050.

Regarding the translation of a full century *carbon* budget into a budget until 2050 only: In the context of 1.5°C degree pathways, that translation happens to be easy, as most 1.5°C compatible pathways tend to show net zero CO_2 emissions by around 2050. A difference among those pathways is whether the emission trajectories assume higher pre-2050 CO_2 emissions that are later offset by net negative CO_2 emissions in the second half of the century. If the reliance on net negative CO_2 emissions shall be minimized, then the translation of a 2013-2100 towards a 2013-2050 carbon budget turns out relatively straightforward, as they are just the same. Only if a heavy reliance on net negative CO_2 emissions is allowed for, the pre-2050 carbon budget would be correspondingly higher than the full century carbon budget.

In equation form:

500 $GtCO_2$	**+0 $GtCO_2$**	**= 500 $GtCO_2$**
The remaining carbon budget from Jan 2013 *until 2100* for a 50% warming to stay below 1.5°C warming relative to pre-industrial levels.	Given the shape of 1.5°C scenarios assessed in IPCC Special Report on 1.5°C, the extra carbon emissions before 2050 depend on the willingness to rely on the assumption of net negative CO_2 emissions after 2050. If that reliance shall be minimized to zero, then no upward adjustments should be performed.	The remaining carbon budget from Jan 2013 *until 2050* for a 50% warming to stay below 1.5°C warming relative to pre-industrial levels.

Step 3: Turning a global carbon budget into a GHG emission budget.

The remaining *carbon* budget is useful as it squarely addresses the most important anthropogenic greenhouse gas emission, namely CO_2. In a policy context, taking into account other greenhouse gases is likewise important however as methane and N_2O emissions as well as industrial gas emissions also contribute to global warming and are part of emission reduction targets across the world. Hence, we here translate the remaining *carbon* budget into a remaining *emissions* budget. While cumulative greenhouse gas emissions have no strict 1:1 relationship with maximal temperature levels (as carbon emissions do), this metric of a remaining *emissions* budget is nevertheless appropriate for the specific context here.

For one, the timeframe over which the non-CO_2 emissions are considered is limited until 2050. Thus, there are limited choices regarding "early" or "late" non-CO_2 emission profiles as basically the trajectories between today's high emissions and future low emissions are limited.

Secondly, this relative short timeframe is roughly comparable to the greenhouse gases' lifetimes. Methane (also taking into account any induced carbon cycle feedbacks) that is emitted towards the beginning of the budget period has comparable warming effects to methane that is emitted towards 2050 in terms of second half of 21st century temperatures. This adds robustness to the derived emission budget.

Thirdly, we use a large set of global integrated assessment model results to derive the typical share of non-CO_2 emissions for any given remaining carbon budget. As can be seen from that analysis, the scope of variation in cumulative non-CO_2 emissions magnitudes is limited. With both the shape and magnitude variations of non-CO_2 emissions limited, an overall remaining emission budget is a useful, robust and highly policy-relevant indicator.

In equation form:

500 $GtCO_2$	**+300 $GtCO_{2eq}$**	**= 800 $GtCO_{2eq}$**
The remaining carbon budget from Jan 2013 *until 2050* for a 50% warming to stay below 1.5°C warming relative to pre-industrial levels as derived above.	Additional non-CO_2 greenhouse gas emissions until 2050 corresponding to that 1.5°C carbon budget when applied up to 2050 on the basis of 411 scenarios from the Special Report on 1.5°C warming. Uncertainty of +- 100 $GtCO_2eq$ (see Figure 2 below).	The remaining *emission* budget from Jan 2013 *until 2050* for a 50% warming to stay below 1.5°C warming relative to pre-industrial levels.

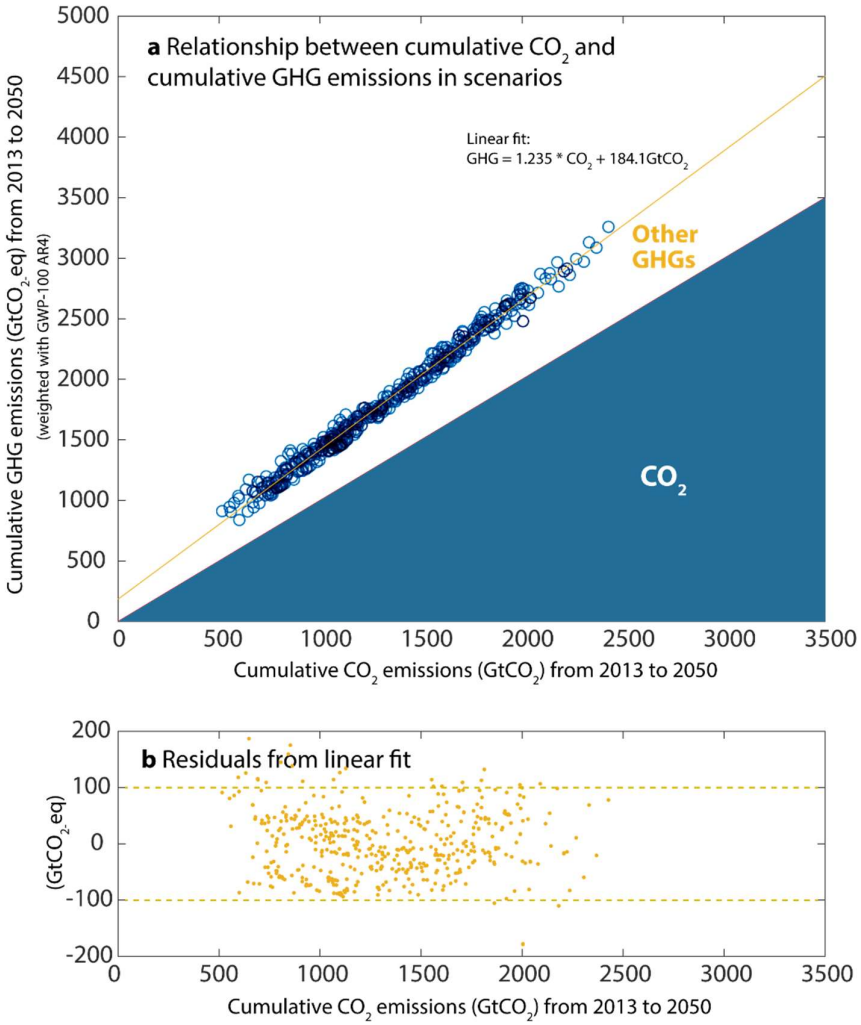

Figure 2 - Analysis of CO_2 versus total cumulative greenhouse gas emissions from 2013 to 2050. As shown in the figure, there is a close relationship between cumulative CO2 and cumulative greenhouse gas emissions. Here, 411 scenarios from the IPCC Special Report on 1.5C scenario database are assessed. The upper plot shows the individual scenarios (blue circles), the 1:1 relationship between the two axis if all non-CO2 emissions were zero (blue triangle) and the linear fit through the data points. The lower panel indicates the uncertainty around the linear fit, indicating a range in between +- 100 GtCO2eq over the investigated timeframe from 2013 to 2050. Non-CO2 greenhouse gases have been weighted by the GWP-100 metric, as used by most countries as part of their NDC pledges and Kyoto Protocol CP2 targets.

Step 4: Deriving the Australian emission budget.

There are a number of ways to derive an Australian share of the global remaining emission budget. A discussion of different approaches to determining Australia's "fair share" of a global budget can be found in the analysis on the 2°C emission budget, i.e. in Meinshausen, Robiou du Pont and Talberg (2018).

***Table 3** - Australia's share of the global budget under five burden-sharing approaches*

Allocation type	Global scenarios with 67% chance of staying below 2°C	Global scenarios with 50% chance of returning to 1.5°C in 2100
Garnaut (2008) method of modified contraction and convergence (as adopted by the CCA)	0.97% (assumed)	not known
Equal per capita convergence	0.73%	0.78%
Equal cumulative per capita	0.68%	0.62%
Capability	0.52%	0.59%
Greenhouse Development Rights	1.19%	0.98%
Constant emissions ratio	1.27%	1.27%

Here, assuming a share of 0.97% pursuant to the assumption of the Climate Change Authority, the remaining Australian emission budgets over the years 2017 to 2050 results as:

(800 $GtCO_2$	**x 0.97%)**	**- 2.3 $GtCO_2$**	**= 5.5 $GtCO_{2eq}$**
The remaining global emission budget from Jan 2013 *until 2050* for a 50% warming to stay below 1.5°C warming relative to pre-industrial levels as derived above.	The assumed Australian share of the 2013 to 2050 emission budget.	The Australian emissions over 2013-2016 (same assumption as in Meinshausen et al., 2018)	The remaining Australian *emission* budget from Jan 2017 *until 2050* for a 50% warming to stay below 1.5°C warming relative to pre-industrial levels.

Step 5: Deriving the Victorian emission budget.

For Victoria, again, various approaches could be followed to determine a fair share of Australian emissions, taking into account current emission levels, historical emissions, GSP, the per-capita emission levels etc. Here, we apply an illustrative 23% share, which is approximately a median fraction across a number of different approaches that can be taken (see Meinshausen, Robiou du Pont and Talberg, 2018).

In equation form

(5.5 $GtCO_{2eq}$	**x 23%)**	**= 1.25 $GtCO_{2eq}$**
The remaining Australian *emission* budget from January 2017 *until 2050* for a 50% warming to stay below 1.5°C warming relative to pre-industrial levels.	The assumed Victorian share of the 2017 to 2050 Australian emission budget. (see Meinshausen et al., 2018)	The remaining Victorian *emission* budget from January 2017 *until 2050* for a 50% warming to stay below 1.5°C warming relative to pre-industrial levels.

Thus, the result of these five derivation steps is that the remaining Victorian emission budget between 2017 and 2050 is 1.25 $GtCO_2eq$ in order to keep warming to below 1.5°C with a 50% chance and on the condition of value judgements by the Independent Expert Panel regarding the Australian and Victorian fair shares.

Appendix: Calculation if the world were to assume 100 GtCO2 net negative emissions in second half of the century.

This Appendix investigates the question how the Victorian carbon budget would change, if the world would bank on the availability of 100 GtCO2 net negative emissions in the second half of the century. Such a net negative emission would be similar in size as the expected permafrost-related carbon cycle feedback of a 100 GtCO2 extra emissions (see Special Report on 1.5C, Table 2.2).

Here, we hence pursue the same calculation steps as above, but assume that the full-century carbon budget will initially be overshot by 100 $GtCO_2$, which relies on the assumption that global net emissions after 2050 will manage to draw a net amount of 100 GtCO2 out of the atmosphere again.

Step 1 hence remains as before:

580 $GtCO_2$	**+200 $GtCO_2$**	**-100 $GtCO_2$**	**- 180 $GtCO_2$**	**= 500 $GtCO_2$**
The remaining carbon budget from Jan 2018 onwards listed in IPCC SR1.5 for a 50% warming to stay below 1.5°C warming relative to 1850-1900.	Enlarging the budget to account for global emissions from 2013 to 2018, so that the remaining budget's starting year is 2013	The remaining budget is adjusted to account for permafrost-related feedbacks of the order of 100 $GtCO_2$. See Table 2.2 in IPCC SR1.5	Reducing the remaining budget to account for a 1.5°C warming target relative to pre-industrial levels, not relative to early-industrial levels.	The remaining carbon budget from Jan 2013 onwards for a 50% warming to stay below 1.5°C warming relative to pre-industrial levels.

Step 2 however adjusts to:

500 $GtCO_2$	**+100 $GtCO_2$**	**= 600 $GtCO_2$**
The remaining carbon budget from Jan 2013 *until 2100* for a 50% warming to stay below 1.5°C warming relative to pre-industrial levels.	It is assumed that world emissions from 2050 to 2100 exhibit a 100 GtCO2 net negative cumulative emissions in order to make up for overshooting the carbon budget by 100 GtCO2 until 2050.	The remaining carbon budget from Jan 2013 *until 2050* for a 50% warming to stay below 1.5°C warming relative to pre-industrial levels.

Step 3 also adjusts by using the relationship shown in Figure 2.

600 $GtCO_2$	**+325 $GtCO_{2eq}$**	**= 925 $GtCO_{2eq}$**
The remaining carbon budget from Jan 2013 *until 2050* for a 50% warming to stay below 1.5°C warming relative to pre-industrial levels as derived above.	Additional non-CO_2 greenhouse gas emissions until 2050 corresponding to that 1.5°C carbon budget when applied up to 2050 on the basis of 411 scenarios from the Special Report on 1.5°C warming. Uncertainty of +- 100 $GtCO_2eq$ (see Figure 2 below).	The remaining *emission* budget from Jan 2013 *until 2050* for a 50% warming to stay below 1.5°C warming relative to pre-industrial levels.

Step 4, the calculation of the Australian budget then becomes:

(925 $GtCO_2$	**x 0.97%)**	**- 2.3 $GtCO_2$**	**= 6.7 $GtCO_{2eq}$**
The remaining global emission budget from Jan 2013 *until 2050* for a 50% warming to stay below 1.5°C warming relative to pre-industrial levels as derived above.	The assumed Australian share of the 2013 to 2050 emission budget.	The Australian emissions over 2013-2016 (same assumption as in Meinshausen et al., 2018)	The remaining Australian *emission* budget from Jan 2017 *until 2050* for a 50% warming to stay below 1.5°C warming relative to pre-industrial levels.

And the last step, Step 5 then becomes:

(6.7 $GtCO_{2eq}$	**x 23%)**	**= 1.53 $GtCO_{2eq}$**
The remaining Australian *emission* budget from January 2017 *until 2050* for a 50% warming to stay below 1.5°C warming relative to pre-industrial levels.	The assumed Victorian share of the 2017 to 2050 Australian emission budget. (see Meinshausen et al., 2018)	The remaining Victorian *emission* budget from January 2017 *until 2050* for a 50% warming to stay below 1.5°C warming relative to pre-industrial levels.

References:

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