Constraining uncertainty of multi-decadal climate projections
GA number 820829
H2020-LC-CLA-2018-2

<table>
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<tr>
<th>Deliverable number (relative in WP)</th>
<th>D5.3</th>
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<td>Deliverable name:</td>
<td>KGSiR on carbon budget estimates updates with the latest insights on forcing, variability and feedbacks</td>
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<tr>
<td>WP number:</td>
<td>WP5</td>
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<td>Delivery due date:</td>
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<td>Responsible scientist / administrator:</td>
<td>Joeri Rogelj</td>
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<td>Contributor(s):</td>
<td>Robin Lamboll</td>
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<td>Internal reviewer:</td>
<td>Charlotte Elliott-Harvey</td>
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1. Changes with respect to the DoA

Minor change of submission date (30/06/2023 to 03/07/2023) for practical reasons, as agreed with the Project Adviser.

2. Dissemination and uptake
This is a public deliverable and will be made available on the CONSTRAIN project website.

3. Short Summary of results (< 250 words)

• Integration of latest scientific evidence further reduces estimates of the remaining carbon budget in line with the Paris Agreement.

• Incorporating additional uncertain factors, such as the warming occurring after net zero CO₂ emissions are achieved further reduces our confidence in the remaining carbon budget still being positive for 1.5°C.

• The estimated remaining carbon budgets requires implementation of deep non-CO₂ emission reductions. Failure to do so further decreases the budgets.

4. Evidence of accomplishment

Knowledge Gains: Summary and Implication Report

July 2023

Understanding estimates of the remaining carbon budget and implications for non-CO$_2$ emissions

Robin D Lamboll, Imperial College London
Joeri Rogelj, Imperial College London

Key messages

• Integration of latest scientific evidence further reduces estimates of the remaining carbon budget in line with the Paris Agreement.

• Incorporating additional uncertain factors, such as the warming occurring after net zero CO$_2$ emissions are achieved further reduces our confidence in the remaining carbon budget still being positive for 1.5°C.

• The estimated remaining carbon budgets requires implementation of deep non-CO$_2$ emission reductions. Failure to do so further decreases the budgets.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 820829.
Context
To a reasonable approximation, the amount of warming we experience depends on the total amount of carbon dioxide ever emitted, irrespective of when it’s emitted (Arias et al., 2021; Canadell et al., 2021). The remaining carbon budget is our best estimate of the amount of carbon dioxide that can be released before we expect to reach a certain temperature at a given probability – for instance, a 50% probability budget for keeping warming to 1.5°C can be a relevant number to inform mitigation requirements under the Paris agreement, as could be estimates of the remaining carbon budget for various probabilities of limiting warming to 2°C as an absolute upper bound of where climate action doesn’t comply anymore with the Paris Agreement. Dividing these budgets amongst nations to form national target requires the application of equity considerations (Matthews et al., 2020; CONSTRAIN, 2019). The remaining budget for 1.5°C is extremely small, making its continued direct application in setting targets challenging (Table 1).

The remaining carbon budget estimates by the Intergovernmental Panel on Climate Change (IPCC) and related reports include an estimate of the amount of future warming that is expected from non-CO₂ emissions. These quantifications use a simple relation between non-CO₂ warming and the maximum total warming that is caused by human activities. However, this relationship is uncertain and requires social projections of when we will emit which gases, unlike the rest of the remaining carbon budget calculations that apply physical science principles.

Table 1 | Estimates of the remaining carbon budget as reported in the Summary for Policymakers of IPCC Working Group 1 contribution to the Sixth Assessment Report (AR6) (IPCC, 2021).

<table>
<thead>
<tr>
<th>IPCC AR6 WG1 SPM</th>
<th>Historical cumulative CO₂ emissions from 1850 to 2019 (GtCO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global warming between 1850–1900 and 2010–2019 (°C)</td>
<td>1.07 (0.8–1.3; likely range)</td>
</tr>
<tr>
<td>1.07 (0.8–1.3; likely range)</td>
<td>2390 (± 240; likely range)</td>
</tr>
<tr>
<td>Global warming since 2010–2019 (°C)</td>
<td>Approximate global warming since 1850–1900 (°C)</td>
</tr>
<tr>
<td>0.43</td>
<td>1.5</td>
</tr>
<tr>
<td>0.63</td>
<td>1.7</td>
</tr>
<tr>
<td>0.93</td>
<td>2.0</td>
</tr>
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</table>

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Summary of Knowledge Gains
Updates to the values underlying remaining budget estimates

To understand implications for remaining carbon budgets, we evaluate the most recent evidence of changes to the Earth’s temperature and recent anthropogenic emissions. These updates contribute to reducing the uncertainty in the remaining carbon budget as we get closer to the temperature limits of interest (Forster et al., 2023), and involve updates to several of the key factors determining the size of carbon budgets (Canadell et al., 2021; Rogelj et al., 2019; Lamboll et al., 2022) (see Figure 1).

The most up-to-date estimate of the remaining carbon budget (Forster et al., 2023) that would provide a 50% probability of limiting global warming to 1.5°C, starting from 2023, now amounts to 250 GtCO₂ (Table 2). We aim to keep producing this repository of updating climate information on a yearly basis going forwards, allowing for much more precise evaluation of where we are climatically, and a better understanding of the implications for climate change mitigation.

Figure 1 | Illustrative schematic of various factors contributing to estimates of the remaining carbon budget, including the CO₂ warming after net zero (ZEC) and the non-CO₂ warming contribution, from (Lamboll et al., 2022). Updates were implemented for the value of historic warming and the non-CO₂ warming contribution. Also the effect of ZEC was explored.
Table 2 | Estimates of the remaining carbon budget updated from the Summary for Policymakers of IPCC Working Group 1 contribution to the Sixth Assessment Report (AR6) (IPCC, 2021) based on updated emissions and global warming (Forster et al., 2023).

<table>
<thead>
<tr>
<th>Update by Forster et al. (2023)</th>
<th>Historical cumulative CO₂ emissions from 1850 to 2019 (GtCO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global warming between 1850–1900 and 2013–2022 (°C)</td>
<td>1.14 (0.9–1.4; very likely range)</td>
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<tr>
<td>2390 (+240; likely range)</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Global warming since 2013–2022 (°C)</th>
<th>Approximate global warming since 1850–1900 (°C)</th>
<th>Estimated remaining carbon budgets from January 2023 (GtCO₂)</th>
<th>Variations in reductions in non-CO₂ emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.36</td>
<td>1.5</td>
<td>500 300 250 150 100</td>
<td>Higher or lower reductions in accompanying non-CO₂ emissions can increase or decrease the values on the left by 200 GtCO₂ or more</td>
</tr>
<tr>
<td>0.56</td>
<td>1.7</td>
<td>1100 800 600 500 350</td>
<td></td>
</tr>
<tr>
<td>0.86</td>
<td>2.0</td>
<td>2000 1450 1150 950 800</td>
<td></td>
</tr>
</tbody>
</table>

Evaluation of impact of non-CO₂ climate uncertainty
As estimates of the remaining carbon budget require an estimate of future non-CO₂ contributions, we assess the impact of our improved understanding of climate effects of non-CO₂ factors that affect the earth’s temperature (Lamboll et al., 2022). A more diligent integration of IPCC AR6 knowledge in simple models of climate change (Nicholls et al., 2021b, 2021a) shows that current warming is influenced more than expected by the aerosol cooling effect. When taken into account in estimates of the remaining carbon budget (Lamboll et al., 2022) this lowers the 1.5°C warming budget across probability levels by about 100 GtCO₂ compared to the pre-existing estimates in the AR6 WG1 report (Forster et al., 2021; Nicholls et al., 2021a; Canadell et al., 2021; Arias et al., 2021).

Evaluation of the impact of the zero CO₂ emissions warming commitment
A further aspect affecting estimates of the remaining carbon budget is the CO₂ warming after CO₂ emissions have been returned to net zero, also known as the zero CO₂ emissions commitment or ZEC (MacDougall et al., 2020). We consider the structural uncertainty in how carbon budgets are calculated by including ZEC uncertainty in the calculation together with other uncertainty contributions and variations (Lamboll et al., 2022). We discover that the estimation of remaining carbon budgets is robust to most forms of structural uncertainty, except for uncertainty in how to interpret the ZEC. Our best estimate of ZEC is zero, but with considerable uncertainty. If ZEC is positive and thus suggests that additional warming will occur after net zero CO₂ emissions are achieved, then it directly contributes to the peak temperature. However, if instead of warming a cooling is expected, it is not a given that ZEC will be realized in time to already markedly lower peak warming. This motivates a non-symmetric consideration of ZEC in estimations of remaining carbon budgets. Such a consideration can potentially reduce the original remaining carbon budget estimate from the IPCC for limiting warming to 1.5°C with at least 50% probability (see Table 1) by about a quarter, and the 50% remaining budget for 2°C by over 10%.

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Combining sources of uncertainty
In most analyses, each type of uncertainty is treated separately. It’s unclear how to combine geophysical uncertainty around the impact of different gases with social uncertainty about what the emissions levels of these gases will be. However, uncertainties that are from geophysical origin can be combined. We find that the combination of geophysical uncertainties is enough to make 0 fall within the one standard deviation uncertainty for the 50% 1.5°C warming budget, effectively suggesting that the remaining carbon budget for limiting warming to 1.5°C with at least 50% probability might already be exhausted today under certain assumptions.

Non-CO₂ mitigation efforts required for being compatible with remaining carbon budget estimates
The social uncertainty in non-CO₂ emissions whose warming reduces estimates of the remaining carbon budget is not quantified in detail to date. This leaves open the question of which emissions reductions are implicitly assumed in estimations of remaining carbon budgets. This gap is closed in as-yet unpublished work by CONSTRAIN, which quantifies the implied emissions reductions of major individual non-CO₂ gases. Reported carbon budgets for 1.5°C assume that total methane emissions will decline by half between 2020 and 2050. For 2°C, total methane reductions are assumed to be smaller, yet still lower by a third in 2050 compared to 2020. Methane from agriculture should decline over the same period by 30 or 20% for 1.5°C or 2°C respectively, and nitrous oxide (N₂O) by 20 or 10%. We find that if methane levels do not decline after 2020, the entire updated remaining carbon budget for a 50% chance of 1.5°C would be exhausted by the additional methane warming and about a third of the budget for a 66% chance of 2°C. A much smaller penalty is incurred for not decreasing N₂O. This is because N₂O is a more minor emission and the assumed decreases in N₂O are much smaller than for CH₄, due to the increased difficulty of abatement and use of fertilizer in biofuels.
Implications

- The amount of carbon that can be released consistent with limiting warming to 1.5°C has decreased by about half since the IPCC estimate published in 2021. This change is both due to recent emissions and to updates to our understanding of physics, particularly the global temperature effects of aerosols.
- The 50%-likelihood 1.5°C-compatible remaining carbon budget is now roughly equivalent to six years of current emissions. While exceeding this limit does not necessarily mean the Paris Agreement has been breached, it is a strong reminder that the urgency of climate action is very high. Global emissions must decline sharply and immediately to keep this Paris Agreement temperature goal in sight.
- The uncertainty in the budget is now directly quantified, and the uncertainty of all factors combined with the remaining budget’s tiny size means that we are no longer confident that the remaining budget for 1.5°C is positive at present. This presents challenges for the use of 1.5°C-compatible remaining carbon budgets in a policy setting, and motivates international clarity on how the Paris Agreement treats temperature pathways that overshoot the 1.5°C target but then return to it.
- The level of effort required to limit warming below 2°C has decreased more moderately. To retain a 90%, 60% and 50% chance of staying below this limit we have 13, 17 and 30 years of current emissions.
- A high level of effort is required to ensure that non-CO₂ emissions, and CH₄ emissions in particular, decline in the near term. These reductions are required both from agricultural sources (reducing by around a quarter between 2020 and 2050) and particularly from fossil fuels (which must more than half by 2050) in order not to further reduce the remaining budgets.
- A decline in levels of N₂O is helpful for meeting climate targets, but a strong decline is not assumed by the majority of modelled pathways compatible with the Paris Agreement and the corresponding remaining carbon budget estimates.
References


Nicholls, Z., Meinshausen, M., Forster, P., Armour, K., Berntsen, T., Collins, W., Jones, C., Lewis, J.,

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About this Knowledge Gains: Summary and Implication Report

CONSTRAIN’s Knowledge Gains: Summary and Implication Reports outline CONSTRAIN’s contributions to the peer reviewed literature (knowledge gains), and summarise the implications for both the scientific community and broader society. This report and other CONSTRAIN publications are available at http://constrain-eu.org.

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How to cite


About CONSTRAIN

The 2015 Paris Agreement sets out a global action plan to avoid dangerous climate change by limiting global warming to well below 2°C, whilst pursuing efforts to limit warming to 1.5°C. However, predicting how the climate will change over the next 20-50 years, as well as defining the emissions pathways that will set and keep the world on track, requires a better understanding of how several human and natural factors will affect the climate in coming decades. These include how atmospheric aerosols affect the Earth’s radiation budget, and the roles of clouds and oceans in driving climate change.

The EU-funded CONSTRAIN project, a consortium of 14 European partners, is developing a better understanding of these variables, feeding them into climate models to reduce uncertainties, and creating improved climate projections for the next 20-50 years in regional as well as global scales. In doing so, CONSTRAIN will take full advantage of existing knowledge from the Sixth Phase of the Coupled Model Intercomparison Project (CMIP6) as well as other Horizon 2020 and European Research Council projects.

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