Carbon budget

https://doi.org/10.1038/s41558-023-01846-7

Estimating vanishing allowable emissions for 1.5 °C

Benjamin M. Sanderson

Check for updates

The remaining carbon budget for 1.5 °C has been a highly discussed tool to communicate the urgency of efforts needed to meet the Paris Agreement. Now, research reassesses IPCC estimates, suggesting that ongoing near-flat emissions and methodological choices can make big relative differences to the tiny remaining 1.5 °C budget.

Time to avoid breaching the Paris Agreement thresholds is running out, but how much time do we have? Perhaps the most powerful climate communication message since the signing of the Paris Agreement has been the understanding[1] that each tonne of emitted carbon dioxide (CO_2) brings us incrementally closer to the 1.5 °C limit that the world has committed to try to pursue efforts to avoid. Budgets associated with different warming levels (most notably the 1.5 °C and 2.0 °C thresholds) have been calculated in recent IPCC reports[2], by combining lines of evidence relating to recent warming and emissions rates with estimates of Earth-system response parameters. However, these calculations (and their communicated uncertainties) can become outdated as new information becomes available, and they are subject to methodological assumptions. Now, writing in *Nature Climate Change*, Robin Lamboll and colleagues[3] reassess assumptions in the methodology used to compute carbon budgets in the IPCC Sixth Assessment Report (AR6) Working Group I (WGI) assessment, and find that a number of these assumptions make significant relative changes to a 1.5 °C budget.

The work by Lamboll and colleagues makes for uncomfortable reading for policymakers, ostensibly halving the best estimate for the remaining carbon budget (RCB) cited in the 2023 IPCC AR6 from 500 $GtCO_2$ to 250 $GtCO_2$. The authors suggest that 45% of this reduction comes from ongoing anthropogenic emissions since the IPCC reference date of 2020, with emissions growing every year following the brief COVID-19 pandemic dip[4]. The rest of the reduction comes from methodological updates relating to model choices and the estimate of warming due to gases other than CO_2.

Lamboll and colleagues conclude that the budget will most likely be exhausted within 6 years of current emissions, but this does not

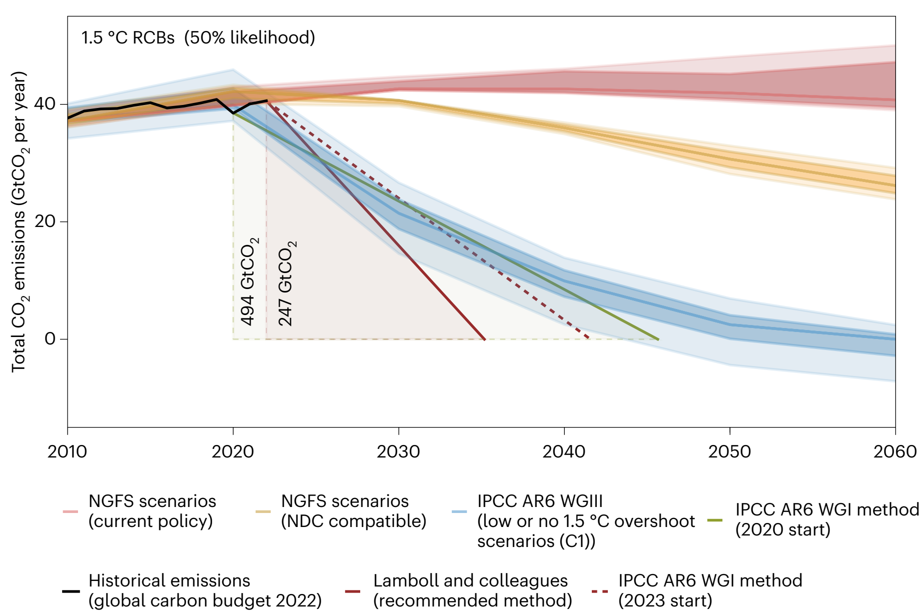

Fig. 1 | An illustration of the RCBs detailed in the IPCC AR6 WGI assessment and by Lamboll and colleagues. Budgets are illustrated by linear declines in CO_2 emissions to 0 from observed estimates in 2020 or 2023 (ref. 4), such that the integral of emissions under the line is equivalent to the reported RCB. The dashed red line represents the IPCC AR6 RCB budget, minus emissions from 2020–2023. Different scenarios are shown for context, where solid central lines, dark shading and light shading represent the median and 25–75th and 5–95th percentile ranges, respectively. The blue-shaded scenario range is from the IPCC AR6 WGIII (ref. 6) scenario database, showing the distribution of scenarios that meet the C1 classification of low or no overshoot of 1.5 °C. Yellow and red scenario ranges show the Network for Greening the Financial System (NGFS) scenarios[7], illustrating nationally determined contribution (NDC)-compatible scenarios and current policy scenarios, respectively.

mean that 1.5 °C of warming will be achieved on that timescale. The warming we experience today has occurred due to a combination of historical emissions of greenhouse gases and aerosols, together with natural processes (solar cycles and volcanoes) and natural variability. As such, warming from greenhouse gases today is partially compensated by cooling from aerosols[5], and the strength of this masking is a key uncertainty. However, the technological shifts needed to reach net-zero CO_2 emissions will also impact other greenhouse gas emissions. Lamboll and colleagues suggest that this will result in an additional warming of 0.1–0.2 °C at the time of net zero, which needs to be subtracted from 1.5 °C before the RCB can be calculated. Altogether, this means that if emissions remain at current levels and the masking effect remains constant, the RCB will be exhausted a few years before the 1.5 °C warming level is reached.

The budgets can be illustrated in an idealized way by considering a linear decline of CO_2 emissions from present-day levels to 0 (Fig. 1). This framing illustrates that the original IPCC AR6 WGI assessment budget (calculated from 2020) implied a net-zero date of 2045 if emissions continued to fall post-COVID-19 pandemic, a decline broadly in line with the most ambitious climate scenarios considered in AR6 with no or low overshoot of 1.5 °C. The budget determined by Lamboll and colleagues, however, is consistent with net-zero CO_2 emissions being achieved in 2034. This is vastly more ambitious than current implemented global climate policies and nationally determined contributions, but also significantly earlier than scenarios considered in the IPCC AR6 Working Group III (WGIII) assessment[6] that avoid significantly exceeding 1.5 °C (most of these reach net zero between 2050 and 2060 (Fig. 1), in line with global adoption of mid-century net-zero targets[7]). Thus, if Lamboll and colleagues are correct, mid-century net-zero targets are insufficient to prevent an overshoot of 1.5 °C.

The implications depend on the accuracy of the new estimate. Apart from accounting for recent emissions, the largest factor in Lamboll and colleagues' reduced budget was a revised estimate of historical aerosol emissions, which impacted the calibration of the simple climate model used in the calculation. However, understanding of how constantly evolving regional aerosol emissions drive global temperature response is still changing[8]. Lamboll and colleagues also considered a second simple climate model, which simulated a 30% larger RCB than the model used in the IPCC AR6 WGI assessment (the results of the two models were averaged for the headline result). This is indicative that model assumptions play a significant role, and a comprehensive exploration of how calibration uncertainties map onto budget uncertainties has yet to be conducted.

The approach used in this work is also not the only way to compute a carbon budget. The approach used in ref. 9 represents the CO_2 portion of the RCB as a function of other quantities calculated in the IPCC report — the transient response to cumulative emissions and the zero-emissions commitment — using simple climate models to compute the non-CO_2 warming correction. This has the pragmatic advantage of improving the self-consistency of the IPCC report, but results are conditional on these structural assumptions. Meanwhile, other approaches for calculating the RCB have been proposed[10–12] that account for the same processes with different calculation structures, and different results[13].

Given all this, how should the IPCC treat the RCB in future reports? The findings laid out by Lamboll and colleagues illustrate that any calculation, no matter how rigorous, is subject to change with revised data and understanding. By performing calculations in the preparation of assessment reports (rather than just assessing budgets in the published literature), the IPCC is conditioning its conclusions on a set of internally assessed assumptions that are liable to change or be challenged. Research papers that aim to publish revisions to IPCC statistics[4,14] address this; however, such efforts risk confusing the self-consistent messaging of IPCC assessments if presented as semi-official 'updates' to the original reports.

This raises the need for the IPCC to consider internally how to keep data current, with a cycle around 7 years and a rapidly evolving climate situation. In the case of the tiny remaining 1.5 °C budget, the work by Lamboll and colleagues illustrates that calculation assumptions and the evolution of non-CO_2 gases can cause relative changes of the same order of magnitude as the budget itself. These problems will only be compounded for the authors of the IPCC Seventh Assessment Report, who will publish their synthesis report with an estimated remaining 1.5 °C budget of 0 (according to this study, at current emissions rates).

Benjamin M. Sanderson ✉
Centre for International Climate and Environmental Research, Oslo, Norway.
✉e-mail: benjamin.sanderson@cicero.oslo.no

Published online: 30 October 2023

References

1. Allen, M. R. et al. *Nature* **458**, 1163–1166 (2009).
2. Canadell, J. G. et al. in *Climate Change 2021: The Physical Science Basis* (eds Masson-Delmotte, V. et al.) 673–816 (IPCC, Cambridge Univ. Press, 2023).
3. Lamboll, R. D. et al. *Nat. Clim. Change* https://doi.org/10.1038/s41558-023-01848-5 (2023).
4. Friedlingstein, P. et al. *Earth Sys. Sci. Data* **14**, 4811–4900 (2022).
5. Jenkins, S. et al. *J. Clim.* **35**, 7873–7890 (2022).
6. Riahi, K. et al. in *Climate Change 2022: Mitigation of Climate Change* (eds Shukla, P. R. et al.) 295–408 (IPCC, Cambridge Univ. Press, 2023).
7. Monasterolo, I., Nieto, M. & Schets, E. *The Good, the Bad and the Hot House World: Conceptual Underpinnings of the NGFS Scenarios and Suggestions for Improvement* (SSRN, 2022).
8. Quaas, J. et al. *Atmos. Chem. Phys.* **22**, 12221–12239 (2022).
9. Rogelj, J. et al. *Nature* **571**, 335–342 (2019).
10. Jenkins, S. et al. *npj Clim. Atmos. Sci.* **4**, 1–10 (2021).
11. Damon Matthews, H. et al. *Commun. Earth Environ.* **2**, 1–11 (2021).
12. Cox, P., Williamson, M., Friedlingstein, P., Jones, C. & Rogelj, J. Preprint at *Research Square* https://doi.org/10.21203/rs.3.rs-2384796/v1 (2023).
13. Rogelj, J. et al. *Nat. Clim. Change* **6**, 245–252 (2016).
14. Forster, P. M. et al. *Earth Syst. Sci. Data* **15**, 2295–2327 (2023).

Competing interests

The author declares no competing interests.