Comments on Jones *et al.*, 2024

We welcome the opportunity to discuss Jones *et al.*'s piece "Bringing it all together: Science and modelling priorities to support international climate policy" and submit our comments for consideration by the authors. Our comments are influenced by our perspective as scientists who work at the interface of policy and science. We call attention to the following open questions because greater clarity is needed on these topics to inform current policy discussions. Below, we provide our suggestions for how the modeling community could address these open questions in finer detail and clarity.

Given that we are on the cusp of exceeding 1.5°C, we believe additional thought and investigation are warranted to better characterize the emissions pathways, risks and impacts (reversible and irreversible) that are associated with temporary overshoot. The modeling priorities outlined in your article are an opportunity to provide clarity on (1) what pathways and actions will produce different overshoot scenarios and (2) what the risks and impacts are from those different overshoot scenarios as a function of rate of warming and magnitude and duration of overshoot (see e.g., Reisinger and Geden, 2023).

1. Overshoot & Risk Frameworks

We appreciate how the authors discuss Earth system tipping points specifically in the event of overshoot (Section 3.1 lines 295-305), but propose that the authors explore overshoot impacts more deeply. As a guide, we point the authors to a framework outlined by Reisinger and Geden (2023). In their article, different aspects of overshoot, including peak temperature, overshoot duration, and their integrated sum, are considered for their impact. They ask how these different overshoot aspects are associated with increasing both reversible and irreversible risks. While an overshoot of peak temperature may be temporary, the impacts are not necessarily reversible. We propose that modeling has a role to play in better characterizing these risks and their uncertainties. What modeling approaches and data (observations) are needed to advance this goal? The non-CO_2 feedback during overshoot (e.g. methane release from wetlands or permafrost, as noted in line 829) seems to be a major concern but the current ESM capacity in simulating CH_4 cycle is low, although some progress is being made with emissions-driven simulations (see e.g., Nzotungicimpaye *et al.*, 2023).

We further propose that both the timeframe of overshoot and the rate of warming are important considerations in this assessment because they may relate to the timeframes over which certain tipping points and HILL events unfold (Ritchie *et al.,* 2023; Lohmann & Ditlevson 2021). The authors already provide important recommendations that HILL events (Section 7.1 lines 604–626) and rapid changes be accounted for in ESMs (Section 9 lines 823-834), and we re-emphasize that these goals be considered within the timeframe of overshoot. To more fully address the role of timeframe, we also suggest the authors investigate both near-term and long-term time windows of overshooting tipping points, such as the next 20, 50, and 100 years, given that this can inform human adaptation. What emission reductions magnitudes and rates plausibly alter the trajectory of these pathways?

2. Overshoot & CDR

Carbon Dioxide Removal (CDR) is a necessary intervention for a temperature exceedance to be temporary, i.e. to be an overshoot. Without CDR or other negative emission or climate intervention, the temperature curve will peak but the accumulated stock of CO_2 and ongoing emissions will prevent the curve from bending down. Despite the critical role that CDR plays in our climate goals, its implementation is still largely theoretical. We appreciate the authors surfacing the issue of CDR in their piece (Section 7.3 lines 692-698; Section 9 lines 823-834), and strongly encourage specific focus around its relationship to and constraints on temporary overshoot.

We suggest that the authors consider the recent commentary by Grubert and Talati (2024), where they outline some of the constraints on CDR feasibility, pointing out that the resources and inputs needed for CDR are depletable, and consequently, their implementation will face limits (e.g., finite below-ground storage). They also distinguish between compensatory and actual net-negative CDR, which acknowledges that the amount of CDR available will also be economically limited. We further encourage the authors to consider limitations on BECCS and the time-dependence of emissions and avoiding pathways that result in emissions of irrecoverable carbon (Goldstein et al., 2020).

Given the importance of effective CDR for limiting temporary overshoot, we encourage the authors to explicitly incorporate these knowable limits and constraints into the CDR scenario-making using IAMs (Ramanathan *et al.*, 2021). What do these constraints mean for limitations on the amounts and rates of CDR? How do these feasibility and efficacy limitations place a constraint on the magnitude and timing of overshoot? What are the potential implications for other forms of negative emissions or climate interventions in the context of temporary overshoot and meeting climate goals?

Even assuming future CDR feasibility, there is significant uncertainty over the timing and magnitude of its temperature impact. CO_2 removed will have a different temperature impact than if an equivalent amount of CO_2 were never emitted (Zickfeld *et al.,* 2023). As a result, preventing CO_2 emissions could limit peak warming better than removing an equivalent amount of CO_2 through CDR methods. This asymmetry in impact may be due to a variety of factors, including the timing of emissions relative to removals, the effects of co-emitted non-CO_2 pollutants, inertia in the climate response, differences in the climate background state, or biogeophysical effects of CDR. Following suggestions made by Zickfeld *et al.* (2023), we encourage the authors to use ESMs to integrate these different factors and increase certainty about the warming impacts of different CDR scenarios (e.g., reforestation vs. DAC).

Distinguishing these non-interchangeable impacts will be essential for clarifying the overshoot peak, timing, and duration of a given pathway.

3. Clearer differentiation between Emulators and ESMs

Given our above recommendations for assessing overshoot warming levels and their impacts, we raise for careful consideration the limitations of climate emulators in these assessments. To what extent can emulators assess the risks associated with overshoot and the feasibility and efficacy of negative GHG emissions? Are there fundamental processes missing from emulators (such as HILL) that would limit their value in such assessment?

4. Clearer differentiation between C1 and C2 overshoot scenarios

IPCC AR6 WGIII established an implicit near-term temperature goal by differentiating between overshoot scenarios: one category of scenarios that stay below 1.5C in 2100 with no or limited overshoot (C1) and the other category of scenarios with high overshoot (C2). We encourage the authors to develop an ensemble of pathways that would elucidate the potential value of an explicit near-term climate goal.

Additionally, more clarity is needed to differentiate among low and high overshoot scenarios. How can improvements in modeling approaches and scenario design better inform this differentiation and its implications for climate policy? Does the realization of different risk levels divide the ensemble into distinct overshoot categories? We further encourage finer differentiation between categories based on their CDR assumptions, particularly for amounts of CDR required by 2050 and 2100. Such recategorization would ideally reflect key CDR differences that are made ambiguous by the current classification based on peak temperature. Finally, consider that more than two categories may be needed to distinguish scenarios along these policy-relevant dimensions.

We thank the authors for raising these questions and appreciate the opportunity to provide comments on how the modeling community can further inform the climate policy discussion on these issues.

Gabrielle B. Dreyfus, Chief Scientist, Institute for Governance & Sustainable Development

Julie S. Miller, Research Associate, Institute for Governance & Sustainable Development

Alyssa Hull, Research Associate, Institute for Governance & Sustainable Development

References

Goldstein A., *et al.* (2020) *Protecting irrecoverable carbon in Earth's ecosystems*, NAT. CLIM. CHANGE 10(4): 287–95..

Grubert E. & Talati S. (2024) *The distortionary effects of unconstrained for-profit carbon dioxide removal and the need for early governance intervention*, CARBON MANAGEMENT 15(1): 1–21.

Lohmann J. & Ditlevsen P. D. (2021) *Risk of tipping the overturning circulation due to increasing rates of ice melt*, PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES 118(9): 1-6.

Nzotungicimpaye C.-M., MacIsaac A. J., & Zickfeld K. (2023) *Delaying methane mitigation increases the risk of breaching the 2 °C warming limit*, COMMUN EARTH ENVIRON 4(1): 1–8.

Ramanathan, V., Xu, Y. & Versaci, A. (2021) *Modelling human–natural systems interactions with implications for twenty-first-century warming*, NAT SUSTAIN 5: 263-271.

Reisinger A. & Geden O. (2023) *Temporary overshoot: Origins, prospects, and a long path ahead*, ONE EARTH 6(12): 1631–1637.

Ritchie P. D. L., Alkhayuon H., Cox P. M., & Wieczorek S. (2023) *Rate-induced tipping in natural and human systems*, EARTH SYSTEM DYNAMICS 14(3): 669–683.

Zickfeld K., MacIsaac A. J., Canadell J. G., Fuss S., Jackson R. B., Jones C. D., Lohila A., Matthews H. D., Peters G. P., Rogelj J., & Zaehle S. (2023) *Net-zero approaches must consider Earth system impacts to achieve climate goals*, NATURE CLIMATE CHANGE 13(12): 1298–1305.