Response to the editor and reviewers

We thank the editor and the three reviewers for the critical assessment of our work and their very helpful and constructive comments. We have addressed all comments point by point and revised our manuscript accordingly.

Reviewer 2

The study estimates emissions pathways that are adjusted to be compatible with temperature targets, referred to as Adaptive Emission Reduction Approach (AERA) using AERA-MIP, made up of 13 full Earth system models, 2 intermediate complexity Earth system models and 1 ocean general circulation model coupled to a carbon cycle emulator. The analyses of AERA-MIP are reported here and provide compatible emission pathways and remaining carbon budgets, together with ocean and land carbon responses. The responses are shown for model means and the model ranges, as well as including ensemble means and ensemble ranges to reveal internal variability where appropriate. The study is very comprehensive, thorough and impressive.

We thank the reviewer for the positive assessment of our manuscript.

I only have minor comments, but given the importance of the study I recommend that these comments are taken on board to aid communication:

1. There is a statement (L177) that the future CO2 emissions curve compatible with a temperature target is largely insensitive to the non-CO2 radiative forcing and land-use changes. As long as this statement is representative of the study (as this seems slightly surprising to me), then I recommend making more of this statement and discussing the implications in the Conclusion and perhaps including in the Abstract.

There seems to be a misunderstanding, as we refer to CO_2-fe emissions in the text, not CO_2 emissions. The CO_2-fe emissions are largely insensitive to the chosen land use and non-CO_2 forcings, as demonstrated by Terhaar et al. (2022), Jenkins et al. (2018), Allen et al. (2018), and Smith et al. (2021). We have extended our description of CO2-fe emissions in the Methods (or in a new box) to avoid misunderstanding. We do not wish to reiterate this finding in the abstract of this paper.

2. The methodology is clearly described and novel, but does overlap with a prior study of Goodwin et al. (2018a) introducing “Adjusting Mitigation Pathways”. The present approach does extend the prior study of Terhaar et al. (2022a). The text states the limitations of the Goodwin et al. (2018a) approach, but does not outline the similarity in the two approaches. Further explanation would be helpful to the wider community.

We modified the text to:

“*Such adaptive approaches have been proposed and tested with reduced complexity models running forward from the present day, and offer promising potential. Goodwin et al. (2018a) introduced the ‘Adjusting Mitigation Pathways” method using a climate box model. In this approach, the remaining carbon budget to a predefined warming target is estimated by using the near-linear relationship between warming and cumulative carbon emission from a historically forced simulation. Then the remaining budget is distributed in the future and reassessed every ten years.”*

and..

"*Even though the philosophy of AERA is similar to the Adjusting Mitigation pathways approach (Goodwin et al. 2018a), AERA provides smoother emission pathways, incorporates non-CO_2 agents, always stabilizes at the warming targets within +/- 0.2°C, and can also be applied to run simulations that temporarily overshoot the warming target."*

3. Please include any caveats about the set of Earth system models that are included in the study, so that there is clarity about any limitations to the approach. For example, there is probably a large range in the climate feedbacks in your model set and limitations in the closures of some carbon cycles particularly for the land, which might then affect the estimates of the remaining carbon budget.

We have added the following caveat paragraph to the discussion section:

"Even though our analysis is based on comprehensive emission-driven, fully coupled Earth system models, a few caveats need to be discussed. First, the models do not include changes in freshwater input from melting ice sheets and the associated impacts on ocean circulation. This additional freshwater input can modulate global and regional temperature and carbon cycle responses (e.g., Bronselaar et al. 2018, Li et al. 2023). However, ice sheet changes are expected to occur on timescales over many centuries, potentially beyond the time horizon of largest reduction in CO2-fe emissions. Nevertheless, the AERA approach would adjust allowable emissions in response to emerging, unforeseen feedbacks when applied to real-world emission and temperature data (Terhaar et al. 2022). Additionally, most models in our study either neglect or poorly represent permafrost dynamics (Burke et al. 2020) and often underestimate soil carbon stocks in the northern high latitudes. Permafrost thaw due to global warming has the potential to release a substantial amount of carbon stored in soil for millennia into the atmosphere over a relatively short period (e.g., Schuur et al. 2015). Therefore, CO2-fe emissions pathways that account for the release of permafrost soil carbon may differ from those shown here, potentially requiring more stringent emissions reduction to achieve the prescribed global warming levels. Future model studies incorporating permafrost soil carbon are necessary to quantify this effect and fully capture the uncertainty in land and ocean carbon-warming feedbacks. Another caveat is the large uncertainties in the non-CO_2 GHG warming feedbacks (Canadell et al. 2021), which are currently not represented in our approach with prescribed non-CO_2 forcing."

4. While the manuscript is very comprehensive, the text is cryptic in places and sometimes not easy to follow due to the large number of acronyms and the choices made of those acronyms. I recommend making variable names more internally consistent, rather than using a range of different symbols to represent variables with the same units. For example, the carbon inventory in (4) includes variables written as E, G and S with subscripts, but when those variables are referred to later in isolation their meaning requires the reader to go back and find their definitions (such as L319). Likewise Table 2 uses REM and EB_2026 and both are in PgC, so unsure as to why the change in symbols used. Sometimes repetition in their definitions would also be helpful to the reader, such as in the final Discussion or Conclusions. I also recommend including a Table to list those variables.

We enhanced the readability of the text by carefully reviewing the manuscript, making slight revisions and reducing the use of acronyms. When an acronym has not been used recently, we now introduce its full name. For example, the sentence on lines 318-320 now reads: *"… as all models have identical prescribed fossil fuel CO_2 emissions*..". We have retained the usage of REB and EB, as REB is commonly employed in literature to refer to the remaining emissions budget of today. However, in the manuscript, we recalculated today's emissions budget based on simulations until 2100-2150. To clearly differentiate between these two emissions budget we opted for two distinct acronyms.

Following our revisions, we no longer believe it necessary to include a table listing the individual variables.

In summary, this study is very impressive and substantial, and will make an important contribution to discussions about the remaining carbon budget, and provide key information for the next IPCC report. Minor editorial work can help in the readability of the study for a wider audience

Minor details

Line 41 Add Goodwin et al. (2018b)

Added.

Equation (6) and (7) add the dt in the integrals to make more explicit.

Added.

Line 243 Overlong sentence including repeated use of but.

Changed to: "*The positive emissions and large model spread during the temperature stabilization phase are consistent with the overall negative but highly uncertain multi-decade temperature response after zero CO2 emissions across a range of EMICs and ESMs (MacDougall et al. 2020; Jenkins et al. 2022b).*"

Line 506. Try to avoid using "it", you know what you mean, but better to be explicit to the reader.

The sentence now reads: "*While the scenario choice does not impact initial estimates of the REB and CO2-fe emission pathways (Terhaar et al. 2022a), the choice does affect fossil fuel CO2 emissions, atmospheric CO2 and the land and ocean carbon sinks (Terhaar et al. 2023).*"