Reply to RC2: 'Comment on essd-2024-103', Anonymous Referee #2, 06 Sep 2024

Review of Global "Greenhouse Gas Reconciliation 2022"

Summary- In this manuscript, authors present an updated dataset based on Deng et al (2022) which presents a dataset that can be used to compare GHG emissions from national inventories to those based on model ensembles. Specifically, their method (amongst other things) uses inversions of modelled estimates from ensembles to reconcile the top-down approach taken by models with the bottom-up inventories. This paper is well written and clearly an important contribution to the literature. I recommend publication after minor revisions. Also, I apologize to the authors and the editors for my delayed review (I was on leave and could not get to this).

Thank you for the positive and very constructive comments. Please find below our replies.

Comments-

1. National LUC CO2 emissions/uptake- From the manuscript, I gathered that the authors have used the LUC emissions/uptake from the Global Carbon Project (specifically atmospheric inversions of the LUC emissions/uptake data). However, starting recently, the GCP has been updated to provide national inventories of LUC emissions and uptake (See the paper from Gasser et al which introduced this- https://bg.copernicus.org/articles/17/4075/2020/). This nationalized data is only available from 3 models. But the reason its important to discuss this is because the Gasser et al. work was done specifically to compare LUC emissions data to national inventories. Can the authors compare the national CO2 data from inversions to the nationalized data? By the way the data itself is available here- https://www.icos-cp.eu/science-and-impact/global-carbon-budget/2022 (See the third spreadsheet). I believe this will add more robustness to the validation.

   Thank you for your detailed feedback. In our study, we primarily compared the top-down atmospheric inversion models with bottom-up national inventory data to explore the methodological framework recommended by the IPCC and the associated uncertainties in the context of global accounting. Regarding the differences between global bookkeeping models and national inventories, previous studies by Grassi et al. (2018, 2021, 2023) have addressed these comparisons and analyzed the sources of discrepancies (mainly definitions). Specifically, aside from inconsistencies in the definitions of managed forest CO2 fluxes, the indirect effects of anthropogenic environmental changes (e.g., the CO2 fertilization effect on vegetation growth and carbon sinks due to increased atmospheric CO2) are treated as non-anthropogenic factors in bookkeeping models, while most national inventories categorize them as anthropogenic. The adjusted atmospheric inversion results in our study are closer in definition to national inventories since the indirect anthropogenic influences have not been separated out.

While we consider that a comparison with bookkeeping models extends beyond the scope of our discussion for the reasons mentioned above, we appreciate the reviewer's suggestion. We have added a paragraph in the main text for further discussion and included a figure in the supplementary materials (building on Fig 8 to include bookkeeping model results) to briefly describe the differences among the three approaches.

Line 766-783:

Figure 8. Net CO2 land fluxes during the period of a) 2011-2015; and b) 2016-2020 in China (CHN), United States (USA), European Union (EUR), Russia (RUS), Canada (CAN), Kazakhstan (KAZ), Mongolia (MNG), India (IND), Brazil (BRA), Democratic Republic of the Congo (COD), South Africa (ZAF), and Australia (AUS). Blue boxes denote the in-situ inversion results from Deng et al. (2022) processed from Global Carbon Budget 2020 (Friedlingstein et al., 2020). Light green boxes denote the in-situ inversion results processed in this study, while dark green boxes denote the satellite inversion results. Black boxes denote the NGHGIs reported values. The white lines in the boxes denote the medians of the land CO2 fluxes. Note that the inversion results here have been adjusted by the lateral flux before the comparison. Additionally, we extend the comparison with national land use change emissions from global bookkeeping models in Fig S4. Further differences between bookkeeping models limited to land use change fluxes and national inventories which additionally account for sinks in managed forests as explained in Grassi et al.

Fig S2 in supplementary materials:

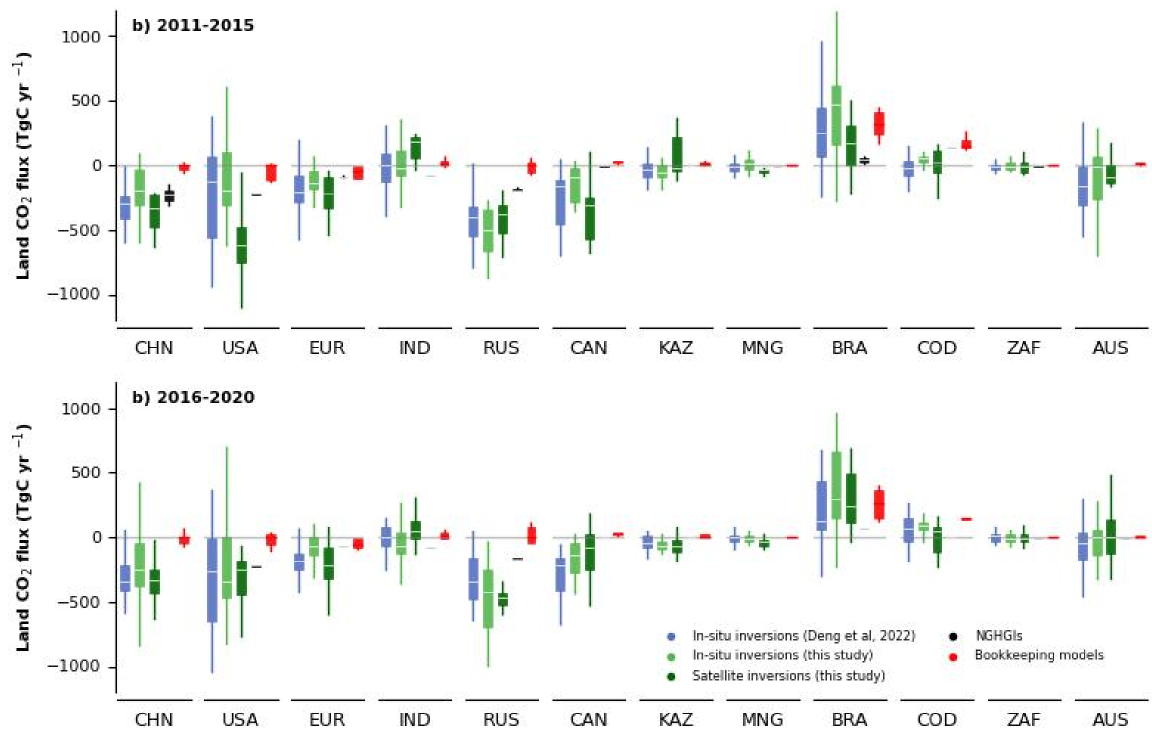

Fig S4. Net CO2 land fluxes during the period of a) 2011-2015; and b) 2016-2020 in China (CHN), United States (USA), European Union (EUR), Russia (RUS), Canada (CAN), Kazakhstan (KAZ), Mongolia (MNG), India (IND), Brazil (BRA), Democratic Republic of the Congo (COD), South Africa (ZAF), and Australia (AUS). *The red boxes denote the national land use change emissions from three global bookkeeping models (i.e., BLUE, H&N2017 and OSCAR) from (Friedlingstein et al., 2023) Other legends are same as Fig 8.*

References:

Grassi, Giacomo, et al. "Reconciling global-model estimates and country reporting of anthropogenic forest CO2 sinks." *Nature Climate Change* 8.10 (2018): 914-920.

Grassi, Giacomo, et al. "Critical adjustment of land mitigation pathways for assessing countries' climate progress." *Nature Climate Change* 11.5 (2021): 425-434.

Grassi, Giacomo, et al. "Harmonising the land-use flux estimates of global models and national inventories for 2000–2020." *Earth System Science Data* 15.3 (2023): 1093-1114.

2. CH4 inversions- For the CH4 inversions, the authors suggest that some inversions optimize within sectors while others provide total gridded emissions. When total gridded emissions are available, prior fluxes are used to allocate emissions to sectors. Could you elaborate which inversions were differentiated by sectors and which were not? Also does assigning sectoral information based on priors involve any uncertainty? Perhaps

this was discussed in the previous paper already and this paper just needs to mention that. But regardless, a discussion of this point would be helpful.

Thanks for the comment. In this study, we utilized seven inversion systems, of which two (MIROC4-ACTM and TM5-CAMS) only provide total emissions. Assigning sectoral information based on prior fluxes does indeed introduce uncertainty, which we emphasize in Section 2.4 of our paper (Line 289-292). We have modified the text accordingly to clarify which inversion systems do not differentiate by sector and to highlight the potential uncertainties associated with using prior information for sectoral allocation：

Line 183-188: *Some inversions optimize emissions in groups of sectors, and others only provide total gridded emissions (MIROC4-ACTM and TM5-CAMS, detailed table can be found in Table S10 in Saunois et al, 2024). For the latter, we computed the emission from each sector within each pixel based on the proportion of the prior fluxes. Such processing can lead to significant uncertainties if not all sources increase or change at the same rate in a given region/pixel.*

3. Wood fuel burning vs fire – I appreciate the discussion by the authors when it comes to discussing the limitations when separating out the emissions from fire vs those from regular wood fuel burning. However, there has been some work recently to separate out wood fuel burning emissions which are non-renewable. Specifically, this paper- https://essd.copernicus.org/articles/15/2179/2023/essd-15-2179-2023.html. Can the authors compare their wood fuel emissions to the emissions as shown in the article here? Once again, this would make the results more robust more than anything else.

Thank you for the suggestion. We compared wood fuel emissions from Flammi et al. (2023) with our adjusted methane inversion results for biomass and biofuel burning (see the figure below), and found that the former generally underestimates the latter. Flammi et al. used wood fuel consumption data from the UNSD Energy Statistics database to provide bottom-up estimates of CO2, CH4, and N2O emissions for 125 countries. Their calculations focus on the non-renewable biomass fraction in cooking, which is country-specific, with an average of 42% across 91 countries.

In our study, as we stated in Line 307-314, the biomass and biofuel burning (BB) inversion category includes methane emissions from wildfires in forests, savannahs, grasslands, peats, agricultural residues, and the burning of biofuels in the residential sector (stoves, boilers, fireplaces). We removed the wildfire component, resulting in anthropogenic biomass emissions (such as those from agricultural residues and dung cakes, which we assume are reported in NGHGIs) and biofuel burning (corresponding to IPCC category 1.A.4 in NGHGIs). Consequently, the scope of our methane inversion flux, after removing wildfires, is broader than that of wood fuel emissions. This is likely a primary reason for the differences observed.

We have included this comparison and related analysis in the revised manuscript and supplementary materials:

Line 314-316:

This method has some uncertainties. First, the partitioning relies on prior fractions within each pixel, and second, emissions from wildfires are counted for in the Biomass and Biofuel burning (BB) inversion category while they are not necessarily reported in NGHGIs. The BB inversion category includes methane emissions from wildfires in forests, savannahs, grasslands, peats, agricultural residues, and the burning of biofuels in the residential sector (stoves, boilers, fireplaces). Therefore, we subtracted bottom-up (BU) emissions from wildfires ($E^{BU}_{wildfires}$) based on the GFEDv4 dataset (van Wees et al., 2022) using their reported dry matter burned and CH_4 emission factors. Because the GFEDv4 dataset also reports specific agricultural and waste fire emissions data, we assumed that those fires (on managed lands) are reported by NGHGIs, so they were not counted in $E^{BU}_{wildfires}$. ***Figure S3*** *presents a comparison between our adjusted BB flux and the wood fuel emissions reported by Flammi et al. (2023). This comparison highlights the broader scope and definition of our adjusted BB flux, illustrating the differences in emissions estimation methodologies.*

Fig S3 in supplementary materials:

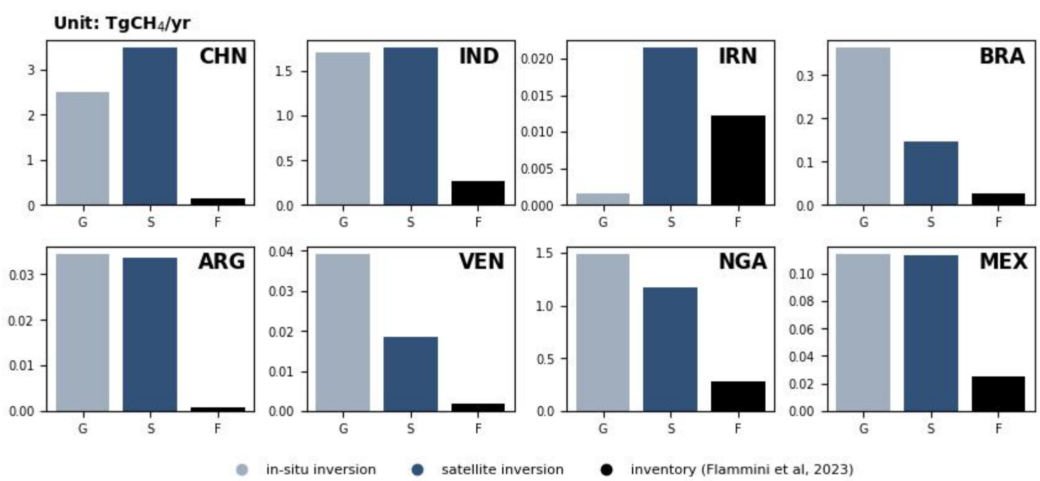

Fig S3. Comparison of the adjusted CH4 inversion flux from the biomass and biofuel burning sector (after excluding wildfires in this study, G: in-situ inversion ensembles; S: satellite-based inversion ensembles) with the bottom-up calculated wood fuel emissions from Flammi et al. (2023) (F). The analysis includes eight countries: China (CHN), India (IND), Iran (IRN), Brazil (BRA), Argentina (ARG), Venezuela (VEN), Nigeria (NGA), and Mexico (MEX). The wood fuel emissions reported by Flammi et al. are generally lower than our estimated emissions. This discrepancy can be attributed to the broader scope of our methane inversion results. Flammi et al. estimate wood fuel emissions for 125 *countries using the UNSD Energy Statistics database, focusing specifically on the non-renewable biomass fraction utilized in cooking. In contrast, our study encompasses a wider range of emissions, including anthropogenic sources such as agricultural residues and dung cakes, while excluding wildfires. This methodological difference likely accounts for the observed variations in emissions estimates.*

4. Lateral carbon transport by crop and wood products- This lateral carbon transport is a really interesting aspect of your work. However, could you highlight this aspect more in the results section? Could you perhaps discuss the extent to which these emissions/uptakes affect total emissions/uptake. Also are these just based on primary product trade (e.g. roundwood) or do they include primary and secondary trade (e.g. roundwood would be primary but wood pulp, sawn wood would be secondary)

We appreciate your interest in the aspect of lateral carbon transport. We have expanded the discussion in the results section to emphasize its impact:
Line 450-455: *In these countries, adjusting inversions by CO2 fluxes induced by river carbon transport and by the trade of crop and wood products tends to lower CO2 sinks, especially for large crop exporters like the USA and Canada. The adjusted net lateral transport fluxes for these countries are 48 (China), 143 (USA), 86 (EU), 63 (Russia), 72 (Canada), 75 (India), and 145 (Brazil) TgC/yr, which represent 20%, 38%, 48%, 11%, 41%, 94%, and 60% of the managed land CO2 fluxes before lateral transport adjustments, respectively.*

Regarding wood products, we clarified in Line 216 that we utilized the bookkeeping model results from Ciais et al. (2021). According to Ciais et al., all direct and indirect products are considered. Specifically, "For roundwood (FAO code 1861), FAOSTAT data were used, and for processed products potentially entering international trade, the GTAP-MRIO data were employed."
We included this explanation in the main text to clarify that both primary and secondary trade (including roundwood, wood pulp, and sawn wood) is accounted for:
Lines 216-220: *Here, we followed Ciais et al. (2021), who used a bookkeeping model to calculate the fraction of domestically produced and imported carbon in wood products that are oxidized in each country during subsequent years, with product lifetimes defined by Mason Earles et al. (2012) and encompassing all products (including roundwood and processed products)*.

References:
Ciais, P., Yao, Y., Gasser, T., Baccini, A., Wang, Y., Lauerwald, R., Peng, S., Bastos, A., Li, W., Raymond, P. A., Canadell, J. G., Peters, G. P., Andres, R. J., Chang, J., Yue, C., Dolman, A. J., Haverd, V., Hartmann, J., Laruelle, G., Konings, A. G., King, A. W., Liu, Y., Luyssaert, S., Maignan, F., Patra, P. K., Peregon, A., Regnier, P., Pongratz, J., Poulter, B., Shvidenko, A., Valentini, R., Wang, R., Broquet, G., Yin, Y., Zscheischler, J., Guenet, B., Goll, D. S., Ballantyne, A.-P., Yang, H., Qiu, C., and Zhu, D.: Empirical estimates of

regional carbon budgets imply reduced global soil heterotrophic respiration, Natl Sci Rev, 8, nwaa145, 2021.

5. Heatmap of countries selected for inversion data- Based on the discussion on lines 99-101 on page 3, it would be interesting to see the countries selected as a heatmap just to understand what portion of emissions are covered globally by emissions type.

   Thank you for the comment. We've added **Fig S1** to illustrate the portion of emissions by each gas:

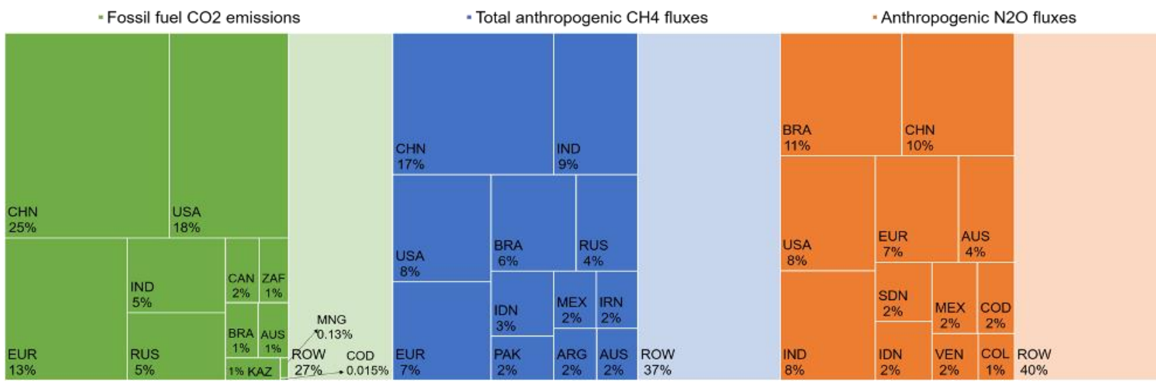

Fig S1. Portion of selected countries' emissions to global fossil CO2 emissions (green blocks), anthropogenic CH4 emissions (blue blocks), and anthropogenic N2O emissions (red blocks).

And we add a citation in **Line 102**:

According to the median of inversion data we used in this study, selected countries collectively represent ~70% of global fossil fuel CO2 emissions, ~90% of global land CO2 sink, ∼60% of anthropogenic CH4 emissions, and ~55% of anthropogenic N2O emissions (Fig S1).

Other minor comments-

1. Lines 92 on Page 3, it seems that there is a typo " Atmosphericnversions" should be separate words.

   Thanks, we've revised it accordingly.

2. Line 170 on Page 7- What do advection and convection schemes mean? Can an explanation be added in a footnote or maybe even be explained in text?

We appreciate your suggestion for clarification. We have added an explanation of "advection" and "convection schemes" in the main text:

Line 174-177: *This ensemble of inversions gathers various chemistry transport models, differing in vertical and horizontal resolutions, meteorological forcing, advection (horizontal transport of air due to wind) and convection (vertical transport) schemes, and boundary layer mixing (detailed characteristics can be found in Table S11 in Saunois et al. 2024).*

3. Line 176 on Page 7- Is there a reference missing for "GAINS"?

We've added the reference to GAINS and completed the sentence:
Line 180-182: *During the production of the inversion simulations, GAINS inventory (Höglund-Isaksson, 2020) was proposed to use another prior for fossil fuel sources instead of using EDGAR v6.*

4. Lines 290-293 on Page 11. " *However, the differences in the calculated results among the four methods were smaller compared to the variations observed in the inversions (see Deng et al. (2022) Fig 9).*" I think you need a sentence after this just summarizing what the differences are before you explain the method used.

We've revised the section to include a concise summary of the differences among the four methodologies, and illustrated that "the differences" would actually be the "uncertainty from the separation method".

Line 295-305: *In our previous study (Deng et al., 2022), four methods were proposed to separate CH_4 anthropogenic emissions from inversions (E_{Anth}^{inv}) to compare them with national inventories (E_{Anth}^{ni}) aiming to discuss the uncertainties in anthropogenic CH_4 emissions associated with the chosen separation methods. These four methods include: (1) summing prior estimates based on inversions for anthropogenic sectors (method 1); (2) subtracting natural emissions from total fluxes (method 2); and (3) subtracting natural emissions derived from other bottom-up assessments from the total inversion flux (methods 3/1 and 3/2, differing only in the bottom-up wetland CH_4 data used). The calculations of anthropogenic emissions by each method were performed separately for GOSAT inversions and in-situ inversions. However, the uncertainty from the separation method is generally much smaller than the variability between different inversion models (see Deng et al. (2022) Fig 9). Therefore, we apply only one method in this study which consists of using inversion partitioning as defined in Saunois et al. (2020):*

5. Lines 443-444 on Page 17- Formatting is off for this sentence- “*post fire biomass changes suggest that fire emissions have exceeded regrowth on average in Western Canada and Alaska until ≈ 2010*”

   Thanks, we’ve corrected the sentence accordingly.