Reviewer: 1

This study presents a sensitivity analysis for a new inversion technique that estimates CO_2 emissions from co-emitted air pollutants (NO_2). The inversion methodology is an interesting way of bypassing challenges in CO_2 remote sensing and takes advantage of the relative ease of NO_2 detection with remote sensing relative to CO_2. While the methodology has been presented elsewhere in the literature with useful applications in real-time greenhouse gas monitoring, a rigorous assessment of its sensitivity to the different input variables is valuable for optimisation moving forwards. The separation of sensitivities into spatial, temporal etc. is particularly nice, especially as we strive for greater and greater resolution in these dimensions. This makes it easy to understand the limitations for specific use cases. In general, the manuscript is of high written and visual quality, and the analysis is sound. I have a few minor comments surrounding the prior NO_x emissions as well as some suggestions below.

Response:

We express our gratitude to the referee for providing constructive and positive feedback on our manuscript. Below, we offer detailed responses addressing each point raised

1. Line 89: What are the sector specific scaling factors? Which sectors and by how much they are scaled (inaccurate) is one of the most valuable outputs of this kind of methodology from a NO_x standpoint. It would be nice to see a plot displaying this in the SI.

Response:

We have added Fig. S2 in SI displaying sectoral correction factors, which mainly range from 0.5 to 1.5, and a brief explanation of this in Lines 127-128.

Lines 127-128: "The overall sectoral correction factors mainly range from 0.5 to 1.5 (Fig. S3)."

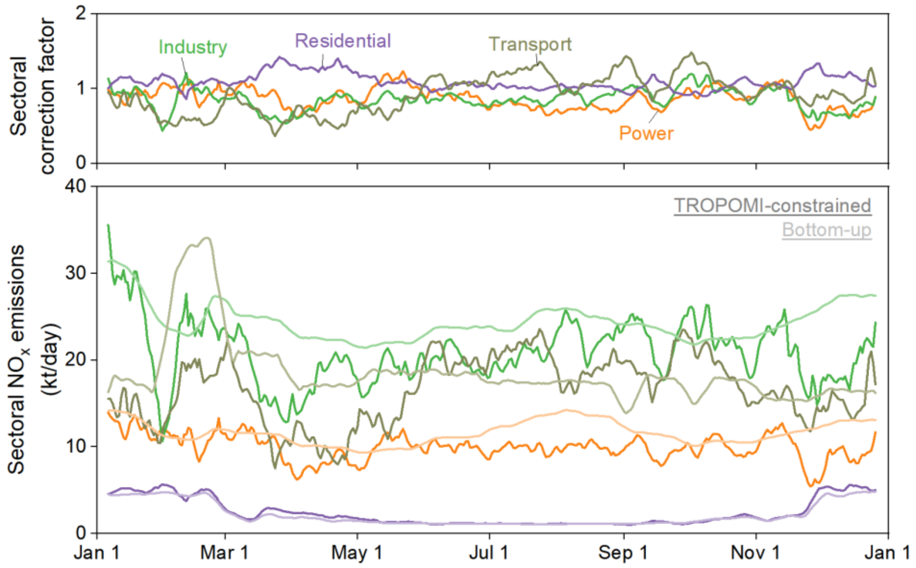

Figure S3. The comparison between bottom-up and TROPOMI-constrained sectoral NO_x emissions (Base inversion). The upper panel shows the sectoral correction factors.

2. Line 94: I have concerns about the accuracy of CO_2-NO_x emission ratios. My knowledge of Chinese emissions inventories is poor. However, in European emissions inventories emission factors for NO_x can be very outdated. Perhaps this is taken into account with the scaling factors discussed in Line 89. I think a discussion of the emissions inventory in addition to the sector specific scaling factors, and even a comparison with other international emissions inventories would be useful e.g. EEA/EMEP, US EPA.

Response:

The CO_2-to-NO_x emission ratios (ERs) from the 2019 MEIC inventory are considered relatively reliable, having been validated in previous simulations (Zheng et al., 2021; Zheng et al., 2020). Although the changes in these ratios since 2019 remain uncertain, we assumed a reduction in NO_x emission factors (EFs) while keeping CO_2 EFs constant from 2019 to 2022 to estimate updated CO_2-to-NO_x ERs for 2022. This assumption aligns with the ongoing emission control measures implemented by the Chinese government. To assess the influence of this assumption, we performed sensitivity tests on varying NO_x EF reduction levels, which demonstrated a significant impact on CO_2 emissions. Additionally, a comparison of our CO_2-to-NO_x ERs with other international inventories (EDGAR and CEDS) shows our values fall within the mid-range.

To make these information clearer, we have added some explanation about the CO_2-to-NO_x emission ratios (ERs) in Lines 135-139 in the Manuscript and a detailed discussion of CO_2-to-NO_x ERs in Text S2 in SI, which includes the method of ERs updates, the sensitivity tests on this settings, and comparison with international emission inventories in China (EDGAR and CEDS).

Lines 135-139: "The CO_2-to-NO_x emission ratios in 2022 are updated by reducing NO_x emission factors (EFs) while keeping CO_2 EFs unchanged based on 2019 MEIC. The default assumption that the reduction rate halves annually is due to the limited potential for further reductions. In contrast, the CO_2 EFs are assumed to remain unchanged, as they are primarily determined by fuel type and combustion conditions (Cheng et al., 2021) (details seen in Text S2)."

Text S2. CO_2-to-NO_x emission ratios

In this inversion system, the CO_2-to-NO_x emission ratios (ERs) are initially derived from the 2019 MEIC inventory, then updated for the target year (2022 in this study) by assuming a specific reduction in NO_x EFs by sector while keeping CO_2 EFs constant. This approach aligns with the ongoing decline in NO_x emissions due to pollution control measures, while CO_2 emissions remain more closely tied to fuel type and combustion conditions (Text S1). Accordingly, the CO_2-to-NO_x ERs are dependent on the reduction ratio of NO_x EFs in this system (represented by the $rNO_{x\,s,i,y}$ in Eq. 5).

The reduction ratio of NO_x EFs first influences the disaggregation of total NO_x emissions to sectors, and then affects the sector-specific conversion from NO_x to CO_2 emissions. To evaluate this impact, we set a gradient test with a NO_x EFs reduction range from 1% to 10% (ef_[-10%, -1%]). Results indicate a notable impact on CO_2 emissions, affecting annual national CO_2 totals by up to 10.7% (Details discussed in Manuscript). This finding emphasizes the need for a more precise approach to setting NO_x emission reduction ratios in future refinements, such as incorporating an iterative adjustment within the bottom-up process to better align bottom-up and TROPOMI-constrained sectoral NO_x emissions (as mentioned in the Discussion).

We further compare the CO_2-to-NO_x ERs of MEIC with some international inventories, including the Emissions Database for Global Atmospheric Research (EDGAR, https://edgar.jrc.ec.europa.eu/dataset_ap81) (Crippa et al., 2020) and the Community Emissions Data System (CEDS) (Mcduffie et al., 2020), for the year 2019. Given the different categorization structures in these inventories, we focus on comparing the overall CO_2-to-NO_x ERs, which are 493.7 for MEIC, 571.5 for EDGAR, and 462.6 for CEDS. The emission factors in MEIC are more spatially and sectorally refined for China, making its CO_2-to-NO_x ERs more representative of China-specific emissions (Zheng et al., 2018).

3. Line 104: Where does this 40% reduction come from? This is not discussed in the text.

Response:

The 40% reduction in simulation is used to quantify the response of NO_2 concentration to the changes in anthropogenic NO_x emission (β), building on previous works. In our previous tests, this perturbation magnitude seems to have a limited impact on final estimates within the tested range of 30-50%. We have added a brief explanation in Lines 110-112 in Manuscript.

Lines 110-112: "The 40% reduction was selected after a series of sensitivity tests, which demonstrated that this perturbation level exerts a limited impact on the β estimates (Zheng et al., 2020)."

4. Line 135: How do the sector scaling factors in Line 89 compare to the -1 to -10 % gradient system? Is -10 % a high enough threshold? Why do you only consider a negative range?

Response:

China has enforced stringent emission controls on anthropogenic NO_x emissions for decades, achieving substantial reductions. Since 2012, NO_x emissions in China have been consistently decreasing; however, as reduction potential diminishes, the rate of decrease has recently begun to slow (Li et al., 2023). For instance, between 2013 and 2017, the annual reduction rate in NO_x emissions was around 5.2%, but it slowed to 3.2% between 2018 and 2020 (Geng et al., 2024). Consequently, a 10% reduction in NO_x emission factors now represents a challenging and idealized scenario.

Regarding the exclusive consideration of negative trends, ongoing emission control policies and actions further underscore the continuous downward trajectory of NO_x emissions, as consistently reported by recent studies (Geng et al., 2024; Li et al., 2023). Thus, a downward shift in NO_x emission factors over time is more consistent with the current policies.

Grammatical:

5. Line 11: Suggest removal of "to prevent irreversible damage". Not needed and air pollution is generally not irreversible.

Response:

We have removed the “to prevent irreversible damage” in Line 12 (original 11) as suggested.

6. Line 24: add “the” after “example,”.

Response:

We have added “the” in Line 24 as suggested.

7. Line 28: Suggest change to “how much, where, and by what activity pollutants are released…”.

Response:

We have modified the Line 29 (original 28) as suggested, as shown below:

Line 29: “The knowledge of emissions, i.e., how much, where, and by what activity pollutants are released into the atmosphere,”

8. Line 61: Suggest change “Our analytical endeavour” to “This study investigates”.

Response:

We have changed the to “This study investigates” in Line 71 (original 61) as suggested.

Line 71: “This study investigates how emission outcomes respond to a variety of sensitivity assessments across temporal, sectoral, and spatial dimensions.”

9. Line 217: Suggest removal of “(all columns except the first one)”. No need to clarify.

Response:

We have removed “all columns except the first one” in Line 251 (original 217) as suggested.

10. Line 258: Suggest replacement of “least” with “low”.

Response:

We have replaced the “least” with “low” in Line 291 (original 258) as suggested.

Figures/Tables:

11. Fig S5: misspelling of national in y-axis label.

Response:

We have corrected the spelling of “national” in the y-axis label in Fig. S7 (original Fig.

S5), as shown below.

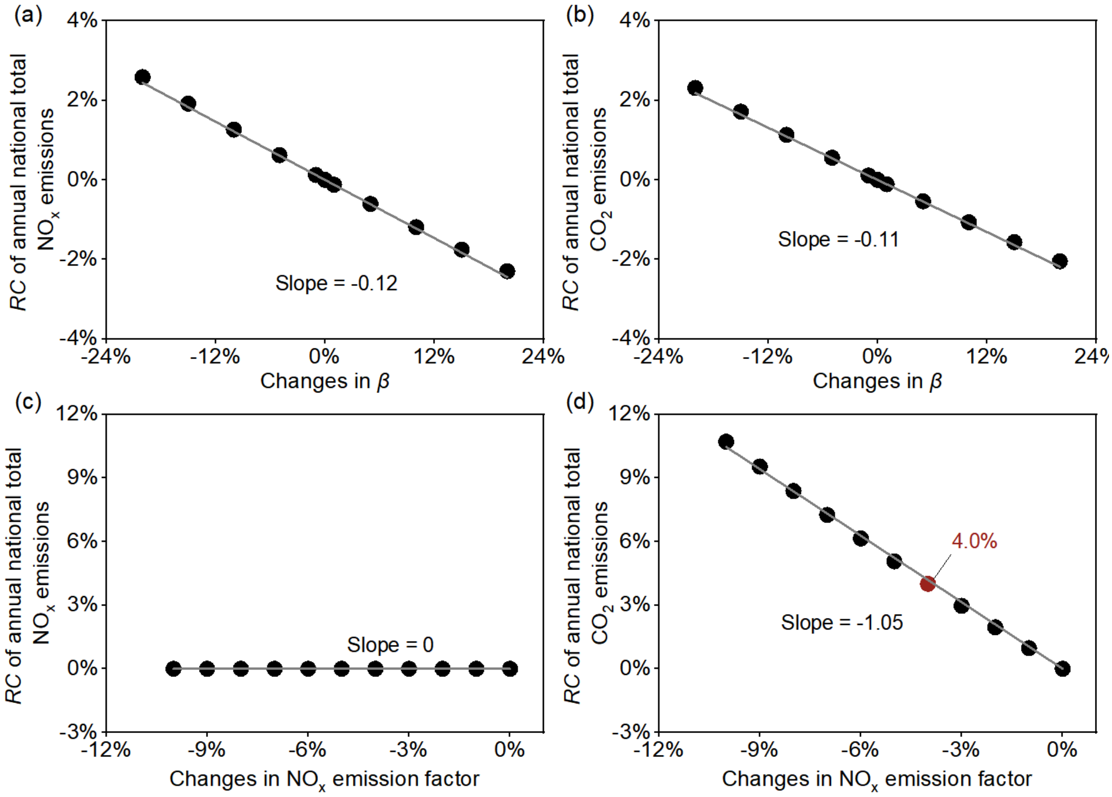

Figure S7. Sensitivity of annual national total NO$_x$ and CO$_2$ emissions to β and NO$_x$ emission factor. (a) and (c) present the estimated NO$_x$ emissions under a ten-level gradient for β and emission factor variations. (b) and (d) are plotted for CO$_2$ emissions as (a) and (c).

12. Fig S11: It would be good to see this plot vs temperature. Why is there such a big drop in March? If it is correlated well, this would be a good verification of the system.

Response:

We have added the heating degree day (HDD) in Fig. S13 (original S11), which shows a good agreement with the residential emission dynamics.

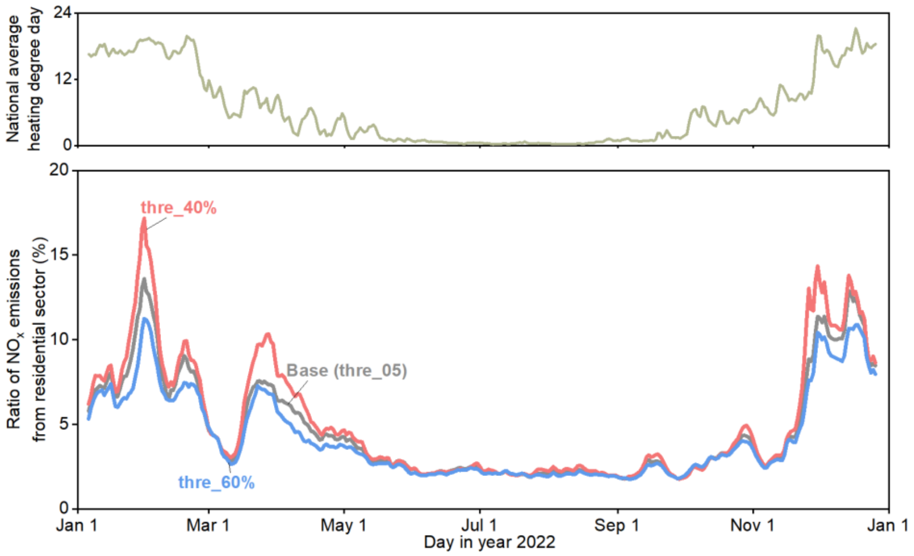

Figure S13. The comparison of proportion attributing total TROPOMI-constrained NO_x emissions to the residential sector. Black, red, and blue lines refer to the Base, thre_40%, and thre_60% inversions, respectively. The upper panel displays the temporal variation of the national average heating degree day.

13. Table 1: Please can you clarify what you mean by "reduction ratio of NO_x EFs halves annually"?

Response:

The "reduction ratio of NO_x EFs halves annually" means that each year's reduction rate for NO_x EFs is set to decrease by half compared to the previous year. For example, if the reduction of NO_x EFs from 2019 to 2020 was 4%, the reduction from 2020 to 2021 would be set at 2%.

We have added an explanation in the Note below Table 1 in Lines 149-150:

Lines 149-150: "*Each year's reduction rate for NO_x EFs is set to decrease by half compared to the previous year. For example, if the reduction of NO_x EFs from 2019 to 2020 was 4%, the reduction from 2020 to 2021 would be set at 2%."

Reference:

Cheng, J., Tong, D., Liu, Y., Bo, Y., Zheng, B., Geng, G., He, K., and Zhang, Q.: Air quality and health benefits of China's current and upcoming clean air policies, Faraday Discussions, 226, 584-606, https://doi.org/10.1039/D0FD00090F, 2021.

Crippa, M., Solazzo, E., Huang, G., Guizzardi, D., Koffi, E., Muntean, M., Schieberle, C., Friedrich, R., and Janssens-Maenhout, G.: High resolution temporal profiles in the Emissions Database for Global Atmospheric Research, Scientific Data, 7, 121, 10.1038/s41597-020-0462-2, 2020.

Geng, G., Liu, Y., Liu, Y., Liu, S., Cheng, J., Yan, L., Wu, N., Hu, H., Tong, D., Zheng, B., Yin, Z., He, K., and Zhang, Q.: Efficacy of China's clean air actions to tackle $PM_{2.5}$ pollution between 2013 and 2020, Nature Geoscience, 17, 987-994, 10.1038/s41561-024-01540-z, 2024.

Li, S., Wang, S., Wu, Q., Zhang, Y., Ouyang, D., Zheng, H., Han, L., Qiu, X., Wen, Y., Liu, M., Jiang, Y., Yin, D., Liu, K., Zhao, B., Zhang, S., Wu, Y., and Hao, J.: Emission trends of air pollutants and CO_2 in China from 2005 to 2021, Earth Syst. Sci. Data, 15, 2279-2294, https://doi.org/10.5194/essd-15-2279-2023, 2023.

McDuffie, E. E., Smith, S. J., O'Rourke, P., Tibrewal, K., Venkataraman, C., Marais, E. A., Zheng, B., Crippa, M., Brauer, M., and Martin, R. V.: A global anthropogenic emission inventory of atmospheric pollutants from sector- and fuel-specific sources (1970–2017): an application of the Community Emissions Data System (CEDS), Earth Syst. Sci. Data, 12, 3413-3442, 10.5194/essd-12-3413-2020, 2020.

Zheng, B., Zhang, Q., Geng, G., Chen, C., Shi, Q., Cui, M., Lei, Y., and He, K.: Changes in China's anthropogenic emissions and air quality during the COVID-19 pandemic in 2020, Earth Syst. Sci. Data, 13, 2895-2907, https://doi.org/10.5194/essd-13-2895-2021, 2021.

Zheng, B., Geng, G., Ciais, P., Davis, S. J., Martin, R. V., Meng, J., Wu, N., Chevallier, F., Broquet, G., Boersma, F., van der A, R., Lin, J., Guan, D., Lei, Y., He, K., and Zhang, Q.: Satellite-based estimates of decline and rebound in China's CO_2 emissions during COVID-19 pandemic, Science Advances, 6, eabd4998, https://doi.org/10.1126/sciadv.abd4998, 2020.

Zheng, B., Tong, D., Li, M., Liu, F., Hong, C., Geng, G., Li, H., Li, X., Peng, L., Qi, J., Yan, L., Zhang, Y., Zhao, H., Zheng, Y., He, K., and Zhang, Q.: Trends in China's anthropogenic emissions since 2010 as the consequence of clean air actions, Atmos. Chem. Phys., 18, 14095-14111, https://doi.org/10.5194/acp-18-14095-2018, 2018.