

RC5

The manuscript by Yang et al. 2025 provides a comparative analysis of China's anthropogenic CO₂ emissions over the period 2000–2023, based on six widely used bottom-up inventories. The topic is highly relevant given the importance of accurate CO₂ accounting for climate change mitigation and policy verification. The dataset selection is comprehensive, and the study offers valuable insights into temporal trends, sectoral contributions, and spatial differences across inventories. Overall, the manuscript is well written and scientifically sound.

Comments:

1. Although comparing multiple inventories is valuable, similar studies have been conducted for China in the past. The authors should make it clearer what distinguishes this work. Does the novelty lie mainly in the inclusion of the most recent versions of the inventories? Or is it the extension to 2023 and more detailed assessment?

Response: We appreciate the reviewer's valuable comment. To clarify the novelty of our work, we have added a short paragraph in the Introduction and a more detailed paragraph in the Conclusion explicitly outlining the main advancements compared with previous studies. Specifically, this study (1) extends the temporal coverage to 2000–2023 and identifies three distinct emission phases reflecting changes in energy policy and structure; (2) evaluates internal inconsistencies within CEADs and recommends using CEADs (sectors) for provincial analyses; (3) reveals significant sectoral spatial allocation differences, particularly between EDGAR and MEIC in the transport sector; (4) quantifies scale-dependent uncertainties, showing that provincial uncertainty (CV) is two to ten times higher than national uncertainty; and (5) demonstrates that CEADs and MEIC yield consistent estimates across nine representative provinces. At the national scale, CAMS exhibits the smallest deviation from the National Greenhouse Gas Inventory (NGHGI), while ODIAC aligns most closely with the six-inventory mean during the study period. These clarifications have been added to Section 1 to highlight the study's novelty and rationale for using the latest inventory versions, and to Section 4 to summarize the new insights contributions.

Revision:

(1) **Section 1, paragraph 4:** *“Moreover, emission inventories are continuously updated to incorporate improved inputs (e.g., activity data, EFs, and refined methodology). Therefore, it is crucial to use the latest versions of the various inventories to capture these methodological updates and better understand the most recent patterns of China's anthropogenic CO₂ emissions.”*

(2) **Section 1, paragraph 5:** *“...Compared with previous studies (Han et al., 2020b; Zheng et al., 2025), we extend the temporal coverage to 2000–2023, enabling a more current and consistent assessment of recent emission trends, inter-inventory discrepancies, and scale-dependent uncertainties across China.”*

(3) **Section 4, paragraph 5:** *“In summary, this study extends previous work by identifying a three-phase trend in China's anthropogenic CO₂ emissions from 2000 to 2023 and quantifying the emission uncertainties (1σ) at both national and provincial levels. At the national level, CAMS*

shows the closest agreement with the government-reported NGHGI, while ODIAC aligns best with the multi-inventory mean over the study period. At the provincial level, the Chinese local inventories, CEADs and MEIC, provide the most consistent estimates for regional studies. Differences in spatial proxies significantly affect the spatial distribution of sectoral emissions, as shown by the contrasting transport emission patterns in EDGAR and MEIC. We also clarify the appropriate use of CEADs for provincial analyses. Our results further underscore the importance of improving the consistency of regional inventories to provide a stronger scientific basis for China's emission mitigation and carbon neutrality policies.

2. The conclusion is very long and contains many technical details. The authors discuss discrepancies between the inventories and ultimately recommend one, the CEADs for sectoral data, but what is the direct impact of this on emissions control in China? The text could end with a strong recommendation to improve regional inventories aimed at supporting mitigation policies.

Response: We thank the reviewer for this valuable suggestion. We agree that highlighting the policy relevance of our findings would strengthen the conclusion. While our study focuses on technical consistency across inventories, the results have clear implications for emissions management in China. We have therefore revised the conclusion to emphasize that improving the accuracy and consistency of regional inventories is essential for tracking progress toward China's dual carbon targets and for supporting evidence-based mitigation policies. Furthermore, to ensure the reliability of inventories, we suggest expanding both ground-based and satellite observations to enable comprehensive independent validation. Specifically, CO₂ flux measurements can be directly compared with bottom-up estimates, while atmospheric CO₂ mole fraction measurements, when integrated with inversion models, yield top-down emission estimates. These top-down results can then be systematically compared with the bottom-up inventories to identify the discrepancies across regional and national scales. We have revised Section 4 to clarify this point.

Revision:

(1) **Section 4, paragraph 5:** "...Our results further underscore the importance of improving the consistency of regional inventories to provide a stronger scientific basis for China's emission mitigation and carbon neutrality policies."

(2) **Section 4, paragraph 6:** "Overall, reliable emissions quantification requires scale-appropriate inventories (e.g., the sectoral CEADs emissions versus the province-based CEADs emissions), improved spatial proxies (e.g., CPED vs. CARMA), and ensemble approaches to mitigate biases, especially in the carbon-intensive eastern regions. It should be noted that this study lacks an observational benchmark to assess these inventories. Future efforts should incorporate direct flux measurements or top-down emissions derived from inversion modeling, in combination with CO₂ mole fraction observations, to compare and constrain bottom-up inventories at both regional and national scales."

Specific comments:

1. Line 183: What is the reason for this stable period between 2012 and 2017?

Response: We thank the reviewer for the question. It is worth noting that China's CO₂ emissions are estimated to have peaked around 2013 according to previous studies, which is why we defined 2000–2013 as the first phase and 2013–2016 as the second in our analysis. The 2013–2016 period represents a short-term stabilization of emissions mainly driven by the adjustment of China's energy structure and industrial upgrades under the 12th Five-Year Plan, together with the implementation of national air pollution control policies since 2013 (Han et al., 2020b; Shi et al., 2022; Zheng et al., 2025). The corresponding text and linear regression statistics in the first and second emission phase has been revised for clarity.

Revision:

(1) **Abstract:** “...The national total CO₂ emissions increase from 3.43 (3.21–3.63) Gt year⁻¹ in 2000 to 12.03 (11.35–12.98) Gt year⁻¹ in 2023, with three growth periods: rapid growth (2000–2013, 0.56 ± 0.013 Gt year⁻¹), near-stagnation (2013–2016, -0.07 ± 0.022 Gt year⁻¹), ...”

(2) **Section 3.1, paragraph 3:** “The increase in CO₂ emissions shows three different phases (Fig. 1, Table 2). The first phase (2000–2013) shows the most rapid growth, with an average growth rate of 0.56 ± 0.013 Gt year⁻¹, driven by industrialization, urbanization, and rising energy demand. In contrast, emissions become relatively stable from 2013 to 2016, with all inventories showing a slight decline (-0.07 ± 0.022 Gt year⁻¹ on average). This short-term stagnation is mainly influenced by the adjustment of energy structure and industrial upgrades under China's 12th Five-Year Plan, and the implementation of air clean policy since 2013 (Han et al., 2020b; Shi et al., 2022; Zheng et al., 2025). ...”

(3) **Section 4, paragraph 2:** “The six inventories in this study agree on three emission phases: a rapid increase of 0.56 ± 0.013 Gt year⁻¹ (2000–2013), a near-stagnation phase of -0.07 ± 0.022 Gt year⁻¹ under the 12th Five-Year Plan and air clean policy (2013–2016), ...”

References:

Han, P., Zeng, N., Oda, T., Lin, X., Crippa, M., Guan, D., Janssens-Maenhout, G., Ma, X., Liu, Z., Shan, Y., Tao, S., Wang, H., Wang, R., Wu, L., Yun, X., Zhang, Q., Zhao, F., and Zheng, B.: Evaluating China's fossil-fuel CO₂ emissions from a comprehensive dataset of nine inventories, Atmospheric Chemistry and Physics, 20, 11371–11385, <https://doi.org/10.5194/acp-20-11371-2020>, 2020.

Shi, Q., Zheng, B., Zheng, Y., Tong, D., Liu, Y., Ma, H., Hong, C., Geng, G., Guan, D., He, K., and Zhang, Q.: Co-benefits of CO₂ emission reduction from China's clean air actions between 2013–2020, Nat Commun, 13, 5061, <https://doi.org/10.1038/s41467-022-32656-8>, 2022.

Zheng, L., Li, S., Hu, X., Zheng, F., Cai, K., Li, N., and Chen, Y.: Spatiotemporal comparative analysis of three carbon emission inventories in mainland China, Atmospheric Pollution Research, 16, 102417, <https://doi.org/10.1016/j.apr.2025.102417>, 2025.

2. Figure 2: Why are the results presented as a five-year average? The CEAD values for the period between 2012 and 2017 are occasionally negative. What factors could explain this phenomenon?

Response: We thank the reviewer for the question. The results in Figure 2 are presented as five-year averages to align with the global stocktake cycle defined by the Paris Agreement, which requires a comprehensive assessment every five years starting in 2023 (UNFCCC, 2015). Accordingly, we have adjusted the baseline year from 2002 to 2003, corresponding to the first global stocktake period. This revision is shown below.

Regarding the slightly negative CEADs growth rate during 2013–2018, this reflects a minor decline in CEADs emissions over that interval (from 10.14 Gt in 2013 to 9.77 Gt in 2018), consistent with the national emission stagnation driven by industrial restructuring under China’s 12th Five-Year Plan and clean air policy. The five-year emission growth shown in Figure 2 is calculated as the difference between the final and initial year divided by five, which naturally yields a small negative value for CEADs in this period.

Revision:

Section 3.1, paragraph 4: “In response to the Paris Agreement’s requirement of a global stocktake every five years starting in 2023 (https://unfccc.int/sites/default/files/paris_agreement_english.pdf), we analyze China’s emissions variation every five years, using 2003 as the baseline year corresponding to the first global stocktake (Fig. 2). The highest growth is recorded in the period from 2003 to 2008 ($> 0.52 \text{ Gt year}^{-1}$) and 2008–2013 ($> 0.45 \text{ Gt year}^{-1}$), followed by a stable period in the years from 2013 to 2018, in which the CEADs even records a slight decline ($-0.01 \text{ Gt year}^{-1}$). Growth then resumed in 2018–2023, averaging $0.21 \text{ Gt year}^{-1}$.”

Section 3.1, Figure 2:

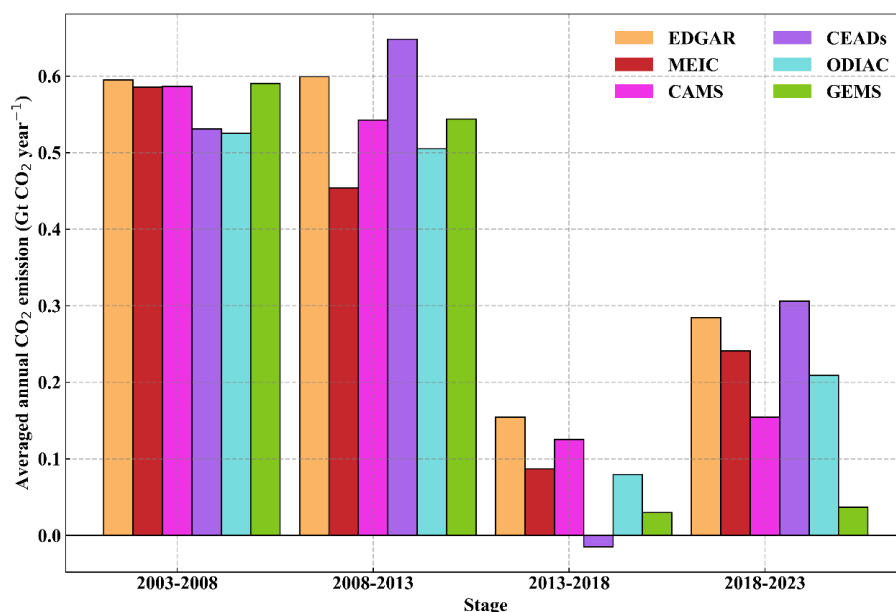


Figure 2. Average annual CO₂ emission growth rate during the five-year periods.

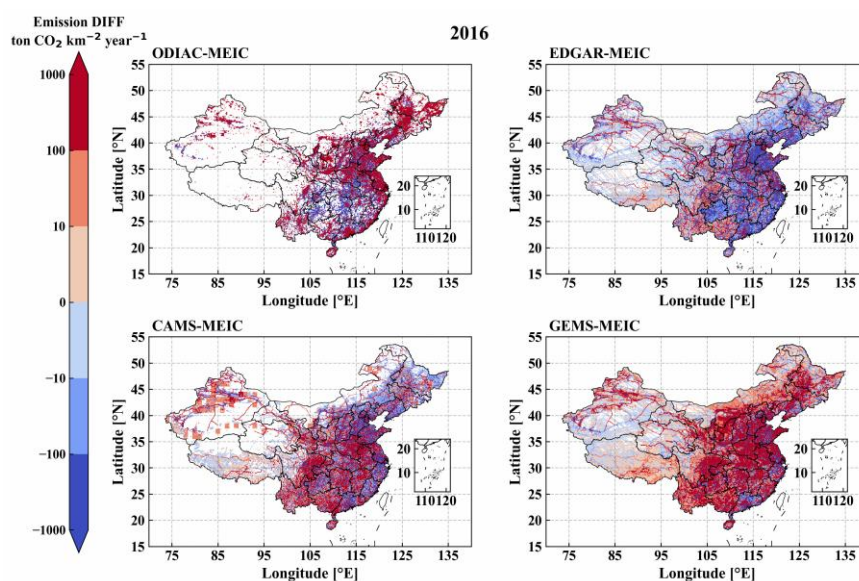
3. Figure 3: has not been cited within the main text

Response: Thank you for pointing out the citation issue for Figure 3. We have carefully checked our manuscript and confirmed that this figure is cited in *Section 3.1, paragraph 5*. The sentence reads: “...*The sectoral CO₂ emissions show that the electricity and heat production sector and the industry and construction sector dominate emissions and together account for over 78% of total emissions (Fig. 3). ...*”.

4. Line 211: Why was the year 2019 chosen as the reference year for comparing spatial patterns in Figure 4? Could this choice be clarified?

Response: We thank the reviewer for the comment. As mentioned in Section 3.2.1, 2019 was chosen as the reference year because it is the most recent year for which all five gridded inventories (ODIAC, EDGAR, MEIC, CAMS, and GEMS) provide spatially explicit emission data. Moreover, 2019 represents a typical pre-pandemic year, unaffected by the COVID-19 lockdowns in 2020–2021. 2019 is free from exceptional events such as the COVID-19 lockdowns, making it a representative baseline for comparison.

Although our manuscript focuses on 2019 due to space limitations, we also conducted preliminary analyses for the third emission phase (2016–2023). As illustrated in the GIF below, the spatial patterns of inter-inventory differences remain generally consistent over time, although the overall magnitude of emissions varying. The only notable exception occurs in the EDGAR–MEIC comparison, where differences in southwestern China shift from obvious positive to negative during 2016–2017. After 2017, the EDGAR–MEIC spatial differences stabilize, and other inventories relative to MEIC show minimal spatial variation throughout 2016–2023.



Temporal evolution of spatial differences in CO₂ emissions between MEIC and other inventories (ODIAC, EDGAR, CAMS, and GEMS) during 2016–2023.

5. Line 234: Could the authors clarify why the MEIC inventory was chosen as the benchmark for Figure 5?

Response: We thank the reviewer for this valuable comment. Among the five gridded inventories (ODIAC, EDGAR, MEIC, CAMS, and GEMS) used in this study, both MEIC and GEMS are constructed using Chinese statistical data. Specifically, the energy consumption data in MEIC and GEMS are derived from the China Energy Statistical Yearbook (CESY) and the National Bureau of Statistics of China (NBS), respectively. Given that GEMS is a newly released dataset (2025) and MEIC has been developed and validated for more than a decade, we selected MEIC as the benchmark for comparison. MEIC is widely recognized and used when studying anthropogenic emissions in China. For example, it has been integrated into the MIX inventory as the Chinese component of the Asian anthropogenic emissions (Li et al., 2017) and was used to develop high-resolution ($1\text{ km} \times 1\text{ km}$) emission maps for 2013 (Zheng et al., 2021). Previous studies have also shown that simulations based on MEIC are more consistent with observations than those using EDGAR or ODIAC in Beijing (Che et al., 2022) and perform better in Xianghe and Xinlong (Yang et al., 2025). We have revised our manuscript for clarifying the rationality of the benchmark choice.

Revision:

Section 3.2.1, paragraph 3: *“To assess spatial consistency, we compared ODIAC, EDGAR, CAMS, and GEMS with MEIC as a benchmark (Fig. 5). MEIC was chosen because it is compiled using local statistics and has been widely applied and validated in previous studies (Li et al., 2017b; Zheng et al., 2021; Che et al., 2022; Yang et al., 2025), making it a reasonable reference for comparison. ...”*

References:

Che, K., Cai, Z., Liu, Y., Wu, L., Yang, D., Chen, Y., Meng, X., Zhou, M., Wang, J., Yao, L., and Wang, P.: Lagrangian inversion of anthropogenic CO₂ emissions from Beijing using differential column measurements, *Environ. Res. Lett.*, 17, 075001, <https://doi.org/10.1088/1748-9326/ac7477>, 2022.

Li, M., Zhang, Q., Kurokawa, J., Woo, J.-H., He, K., Lu, Z., Ohara, T., Song, Y., Streets, D. G., Carmichael, G. R., Cheng, Y., Hong, C., Huo, H., Jiang, X., Kang, S., Liu, F., Su, H., and Zheng, B.: MIX: a mosaic Asian anthropogenic emission inventory under the international collaboration framework of the MICS-Asia and HTAP, *Atmos. Chem. Phys.*, 17, 935–963, <https://doi.org/10.5194/acp-17-935-2017>, 2017.

Yang, H., Wu, K., Wang, T., Wang, P., and Zhou, M.: Atmospheric anthropogenic CO₂ variations observed by tower in-situ measurements and simulated by the STILT model in the Beijing megacity region, *Atmospheric Research*, 325, 108258, <https://doi.org/10.1016/j.atmosres.2025.108258>, 2025.

Zheng, B., Cheng, J., Geng, G., Wang, X., Li, M., Shi, Q., Qi, J., Lei, Y., Zhang, Q., and He, K.: Mapping anthropogenic emissions in China at 1 km spatial resolution and its application in air quality modeling, *Science Bulletin*, 66, 612–620, <https://doi.org/10.1016/j.scib.2020.12.008>, 2021.

6. Figure 7: Could the authors clarify whether the pattern observed for Shanxi Province is unique to this province or if it occurs in other regions as well?

Response: We appreciate the reviewer's careful attention on the pattern observed in Shanxi Province. We generated a provincial heatmap showing the differences between CEADs (provinces) and CEADs (sectors). The provinces are sorted by provincial total emissions in descending order (Fig. S2). The results show that Shanxi is a clear outlier among all provinces, with differences exceeding 900 Mt CO₂ year⁻¹ after 2012, while differences in other provinces remain within 400 Mt year⁻¹. While other provinces show spatially heterogeneous discrepancies, no other region exhibits a pattern of this magnitude. This unique characteristic is why we chose to highlight Shanxi Province in our analysis. Beyond Shanxi, Large differences (>100 Mt year⁻¹) are mostly concentrated in provinces with higher total emissions (top 15 in 30 provinces), with few exceptions (e.g., Xinjiang in 2021). Provinces with lower total emissions (bottom 15) generally show smaller discrepancies (<50 Mt year⁻¹), except for Xinjiang, Guizhou, and Ningxia. Overall, although the spatial pattern is heterogeneous, there is a general tendency for differences to decrease with provincial emission magnitude. We have added this provincial heatmap to the supplementary material and revised the manuscript accordingly.

Revision:

Section 3.3.1, paragraph 1: *“CEADs provides two forms of CO₂ emission estimates for provinces: the “province” series (referred to as CEADs (provinces)), which provides total emissions directly for each province, and the “sectors” series (referred to as CEADs (sectors)), which compiles fuel- and sector-specific emissions before summing them to the provincial totals. Significant discrepancies are observed between these two estimates in some provinces, with Shanxi emerging as a pronounced outlier. After 2012, the difference in Shanxi exceeds 900 Mt year⁻¹, whereas in other provinces it remains below 400 Mt year⁻¹ (Fig. S2). To investigate this divergence, we compare both CEADs estimates with other inventories in Shanxi (Fig. 7a). The results indicate that CEADs (provinces) exceeds CEADs (sectors) after 2008, ...”*

Section 7, Figure S2:

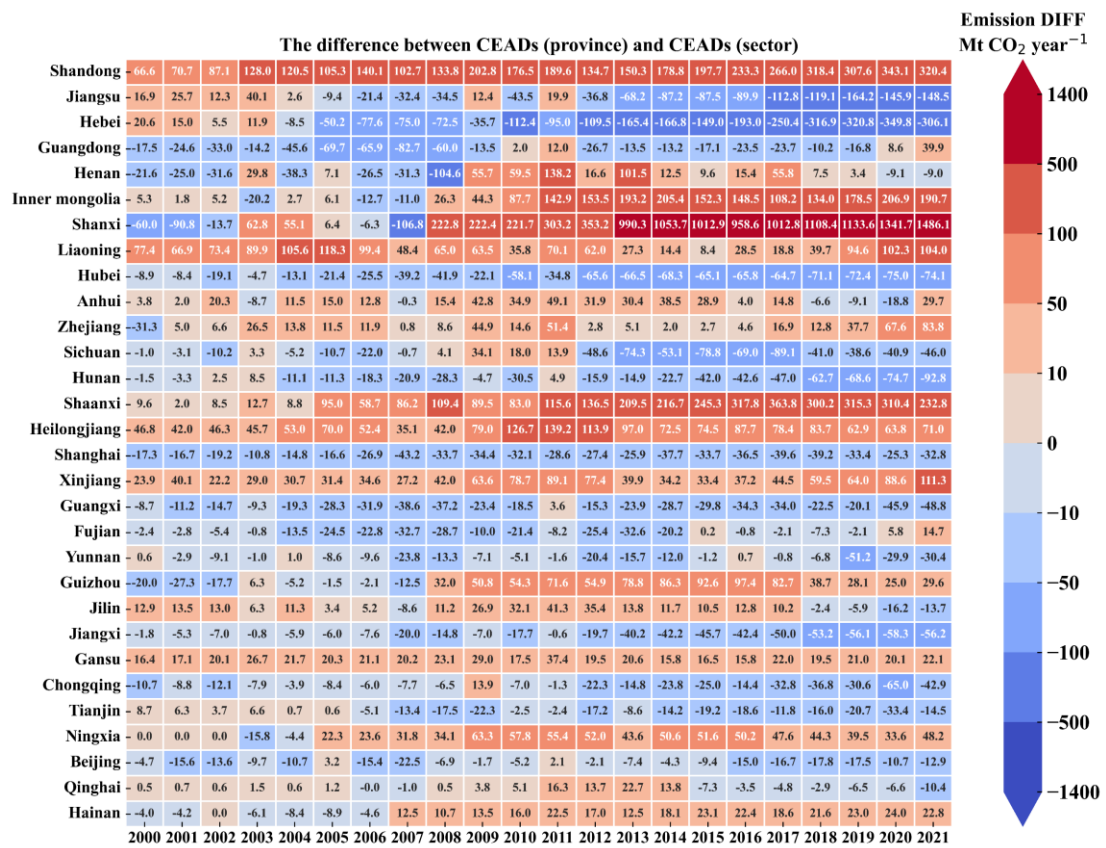


Figure S2. Heatmap of the annual CO₂ emission differences between CEADs (province) and CEADs (sector) for 30 Chinese provinces provided by CEADs during 2000–2021. Provinces are ordered by total emissions from highest to lowest.