Response to Reviewer 1 Comments

This study provides a unique millennium-scale perspective on land-use change (LUC) emissions in China, addressing critical gaps in reconstructing historical LUC data and updating contemporary emissions modeling. While the data and modeling are not perfect at this point, the study has made great improvements to LUC data since the 1000s, and updated carbon densities for current biomass and soil. The manuscript is well-structured and easy to follow, but its contributions and methodological choices require further clarification to strengthen its impact. I would recommend publication after revisions.

Response: Thank you for this comment and your recognition of our manuscript. Your comments enable us to pinpoint issues within the manuscript accurately and provide us with guidance for improvement. I am glad to have such an opportunity to communicate with you. We have carefully revised the manuscript according to your comments and suggestions. For detailed revisions to the manuscript text, please refer to the revised draft where changes are highlighted in red font.

Thanks again for your help in improving the manuscript.

Major Concerns:

Point 1. The study's novelty should be explicitly contextualized. Why is a millennium-scale analysis of LUC emissions critical, given the inherent uncertainties in pre-industrial data? How does this long-term perspective enhance our understanding of anthropogenic impacts on carbon cycling, even when CO2 levels were relatively stable before industrialization? China's uniquely long historical record enables this work, but how might its findings inform global LUC emission estimates, particularly for regions with limited historical documentation?

Response: Thank you for this comment.

Your comment is very important for improving our manuscript. According to your suggestions, we have made the necessary revisions in the introduction to address why we chose the past millennium, what makes this period special, the significance of conducting research over such a long time scale, and whether the results can provide insights or references for other countries and regions. Please refer to lines 71–84 in the main text, where the revised content is marked in red. The revised excerpt is as follows:

"Although most global and regional studies on land-use change focus on the post-industrial era or the past three centuries, China's intensive and extensive land-use activities date back at least a millennium, thus representing a unique historical trajectory (He et al., 2025, 2023). From approximately AD 1000 (coinciding with the Northern Song Dynasty), ecological degradation in China showed a marked rise. This degradation was manifested through multiple pathways: accelerated erosion on the Loess Plateau, recurrent floods in the lower Yellow River Basin, large-scale lake siltation and disappearance in northern China, and progressive soil erosion coupled with natural vegetation loss in the southern hill regions (Wu et al., 2020; Chen et al., 2012). Such millennial-scale land-use transitions would have generated substantial carbon emissions, particularly from deforestation. However, the relatively stable pre-industrial global CO_2 concentrations likely obscured these regionally significant anthropogenic carbon fluxes because localized emissions in areas such as China could have been offset by concurrent carbon sinks elsewhere. Additionally, the full trajectory or specific stages of historical land-use change in China can serve as a "historical analogue" for other developing countries. For many countries and regions, systematically revealing the processes and mechanisms of land-use change and associated carbon emissions—driven by long-term population growth and policy shifts—can help overcome the limitations associated with a lack historical records and reliance on static assumptions."

Point 2. Regarding LUC data: It is challenging, if not impossible, to validate the LUC over the past millennium. The "reliability assessment" of historical LUC data needs elaboration. How does this assessment validate the reconstructed data, given the absence of direct validation methods for pre-industrial periods? Clarify whether this approach evaluates internal consistency, cross-references with alternative proxies (e.g., tax records), or quantifies uncertainty ranges. Please explicitly state what distinguishes the LUC dataset in this study from prior publications by He et al. Is the novelty in data synthesis, spatial resolution, or integration of new historical sources (e.g., tax records)?

Response: Thank you for this comment.

Reliability assessment has always been an unavoidable yet unverifiable aspect of historical land-use reconstructions, as the actual historical conditions cannot be fully known and can only be reconstructed using proxy data. Therefore, the reliability of such reconstructions is typically evaluated by examining the data sources, the rationality of the reconstruction methods, and the degree to which the results align with historical records, historical events, or similar datasets. In response to this issue, a dedicated subsection—2.3.2 Reliability assessment of long-term land-use change data—has been included in this manuscript. This section briefly outlines the above-mentioned aspects to indirectly demonstrate the reliability of the reconstructed data.

Relevant revisions can be found in lines 221–229, 254–258, and 275–277 of the manuscript, and have been marked in red font.

Point 3. Regarding carbon density assumptions: The assumption of static carbon densities over millennia is problematic. While the authors update current biomass and soil densities, pre-industrial carbon stocks likely shifted due to CO2 changes, climatic variability, ecological succession, and human management. Discuss how these dynamics might bias emission estimates and propose strategies to address this in future work (e.g., coupling with DGVM outputs). The carbon density updates in the current work only scratched the surface of the issue, by improving the densities of "current" times. In GCB2024, there are four book-keeping models used, why do you choose H&N or H&C model (I assumed, you did not specify)? Is it because of spatial resolution or any particular features that match well with your current data, like using LUC "state" instead of LUC "transition"? The other three seem to incorporate dynamic carbon densities to some extent (for instance including DGVM biomass data), but also with higher spatial resolution that may not match the provincial level in this study. I would suggest clarifying the rationale in the Methods, AND further discussing the uncertainties in the Discussions. This is not to deemphasize this work, but to urge future improvements.

Response: Thank you very much for your comments. Your feedback is professional, rigorous, and highly valuable for the further revision of our manuscript. It also provides insightful directions for potential future improvements, and we sincerely appreciate it.

First, following your suggestion, we have further clarified the origin of the bookkeeping method used in our study and the rationale for selecting this model in the Methods section (Section 2.3.1). Please refer to lines 192–197 in the manuscript, which have been highlighted in red for easy identification. The revised excerpt is as follows:

"The bookkeeping method (a statistical model) proposed by Houghton and Castanho (2023) was employed to estimate the annual carbon emissions caused by land-use changes in China from 1000 to 2019. Due to data limitations, long-term historical land-use reconstructions in China are primarily constrained to land-use "states" (e.g., total cropland or forest area at national/provincial levels for specific years) rather than spatially explicit land-use transitions. This characteristic, combined with the provincial-level spatial resolution of our data, makes such reconstructions inherently compatible with the bookkeeping model adopted here (Houghton and Castanho, 2023)."

In Section 4.3 Uncertainty Analysis, we provide a detailed discussion on static versus dynamic carbon density, the potential uncertainties associated with using static carbon density values, and directions for future improvements. Specific revisions were made in lines 565–573 of the main text and have been marked in red font. The excerpt is as follows:

"Although modern soil carbon densities were moderately adjusted by incorporating a large-scale soil sampling survey dataset from the post-1949 period in China, pre-industrial carbon stocks likely varied due to shifts in atmospheric CO_2 concentrations, climate fluctuations, ecological succession, and human land management. Vegetation and soil carbon densities were not static over the past millennium. Therefore, using static values to represent historical carbon densities may fail to capture temporal dynamics, thereby introducing uncertainties. Potential biases include overestimating human contributions if climate-driven increases in carbon density are ignored and overestimating modern carbon uptake if long-term baseline declines in carbon stocks are not included. Future studies should explore coupling DGVMs (e.g., LPJ or ORCHIDEE) to simulate combined impacts of historical climate, CO_2 levels, and human activities on carbon density."

Point 4. About uncertainty quantification: The current "uncertainty" section (4.3) primarily discusses limitations rather than quantifying uncertainties. Incorporate a robust quantitative analysis (e.g., Monte Carlo simulations) to assess how data gaps (e.g., historical LUC, carbon density variability) propagate into emission uncertainties. This will enhance the study's rigor and reproducibility. The 4.3 section is not technically an "uncertainty analysis", it is simply discussions of limitations and possible future work.

Response: Thank you for your insightful comments on the uncertainty quantification. We fully agree that the original Section 4.3 focused more on qualitative discussions of limitations and future work, rather than providing a rigorous quantitative uncertainty analysis. To address this, we have implemented the following key revisions.

(1) In the Methods section of the manuscript, we have added subsection 2.3.4, 'Uncertainty assessment,' which elaborates on how we utilized Monte Carlo simulations to assess the uncertainty in carbon emission results. For the full description, please refer to lines 351-362 of the main manuscript. An excerpt is provided below:

"To evaluate the uncertainty in estimating carbon emission fluxes, this study employed Monte Carlo simulations with 1000 iterations. The uncertainty primarily stems from two key parameters: carbon density and land-use change area. For the carbon densities in the forest (aboveground, belowground, and soil) and grassland (aboveground, belowground, and soil) components, the mean and standard deviation were calculated based on input sample data. During the simulations, values for these densities were randomly sampled from normal distributions parameterized based on these statistics measures. Regarding the land-use change area, the original input value for the annual conversion area of each land-use type served as the mean for its sampling distribution, with the standard deviation set to 10% of this mean. Values were then randomly sampled from a normal distribution defined by these parameters in each iteration. Subsequently, in every iteration, the annual carbon emission flux was re-estimated using the parameters sampled in that specific iteration. After aggregating the results from all iterations, the minimum and maximum simulated carbon emission flux values for each year were used to define the uncertainty interval for that year's estimates."

(2) In subsection 4.3, 'Uncertainty analysis,' we plotted the Monte Carlo simulation results as Figure 10 and subsequently analyzed them. For full details, please refer to lines 540-551 of the main text. An excerpt is provided below:

"This study employed Monte Carlo simulations (1000 iterations) to systematically assess the uncertainty in annual carbon emission flux estimates (Fig.11). The results revealed that the average annual uncertainty interval, which was derived from the maximum and minimum simulated carbon emissions, was 18.75 Tg C. This interval exhibited significant interannual variation, ranging from a minimum of 3.77 Tg C to a maximum of 143.67 Tg C. Such variation indicates that the uncertainty in the estimation results increased in years characterized by substantial fluctuations in land-use change data. Overall, the Monte Carlo simulations effectively highlighted the impact of parameter uncertainty on carbon emission estimates and provided a quantitative basis for evaluating the credibility of the carbon flux results. To further constrain parameter variability, future efforts should focus on improving the resolution of measured carbon density data and the reliability of land-use data."

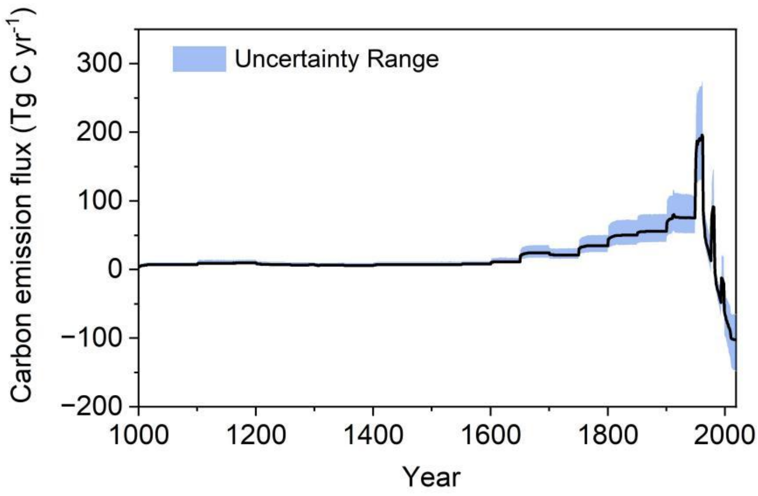

Figure 10. Uncertainty in annual carbon emissions from land-use change

Minor points:

Point 5. "China": this needs to be better defined in this study! You used the current mainland China as the country boundary, and merged the 30+ provinces into 25 regions. I understand your reasoning for compromising here, but you must make this crystal clear in the Abstract and Methods. In Fig. 1, you may also cite specific studies for each map for different dynasties.

Response: Thank you for this comment. I fully agree with your proposal. Revised.

Clear research scope and fundamental units can significantly enhance the manuscript's readability. I have explicitly defined our study area and provincial-level units in both the Abstract (Lines 21-23) and Methods section (Section 2.1 Study Area - Lines 112-115), with additional clarification on the sources of historical territorial and administrative boundaries data provided in Line 124.

For detailed revisions to the manuscript text, please refer to the revised draft where changes are highlighted in red font.

Thank you once again!

Point 6. L171: regarding the bookkeeping model, did you use the Houghton model, or simply used their structure and data? This can be made more explicit.

Response: Thank you. Revised.

The computational structure of Professor Richard A. Houghton's bookkeeping model is relatively simple, as shown in Equation 3. The distinctive feature of this method lies in its parameterization of disturbance-response curves. These curves define the long-term carbon release and sequestration patterns by different vegetation types and their associated soils following land-use conversions, which constitutes the core mechanism of carbon accounting. We obtained region-specific parameters for China from Professor Richard A. Houghton for implementing this carbon budget calculation.

In Section 2.3.1 (Bookkeeping Method), we have explicitly clarified this point by citing that the disturbance-response curves were sourced from Houghton and Castanho (2023). The modifications in the manuscript are located in Lines 211-212 and are highlighted in red font. Since the values of the disturbance-response curves are derived from existing literature rather than our own analysis, they have been compiled in Appendix Table B2.

Point 7. L200: "local expert and knowledge", delete "and"?

Response: Thank you. Revised.

Thank you once again for your help—not only did you improve the overall logic and readability of our work, but you also took the time to pay close attention to the details of the manuscript. We are especially grateful!

Point 8. L206: using tax records is a great idea, but how does this help this particular study? Any quantitative evidence?

Response: Thank you for this comment.

In this study, the cropland data covering dozens of time slices over the past millennium are primarily reconstructed based on historical tax records from successive Chinese dynasties. This approach is fundamentally different from the global datasets and serves as strong support for the higher reliability of our data. It has been well-documented that land-use reconstructions based on region-specific historical records tend to be more accurate than large-scale simulations, especially in regions with rich documentary evidence, such as China.

To address the issue of data reliability, we have explicitly described the sources and general reconstruction processes of historical cropland, forest, and grassland data in Section 2.3.2 (“Reliability assessment of long-term land-use change data”). This section aims to show that the dataset used in our study is currently the only one in China that covers major land-use types over a long time span with high reliability. Therefore, we have deliberately dedicated substantial space in the manuscript to explain the basis and credibility of our data in detail, in order to enhance the confidence of reviewers and readers. (Line 219-279)

Regarding the suggestion to provide quantitative evidence, this manuscript focuses on the application of our reconstructed land-use datasets. The quantitative procedures of the data have been comprehensively presented in a series of previous publications by our team. These key references have been listed in Table 1 for readers and reviewers to trace and examine if needed.

Do you agree with our response? If you have any questions, please raise them again. We will continue to make targeted modifications in the second round. Thank you once again!

Point 9. L224: this is out of context, what exactly is “inverted S-shaped” relationship?

Response: Thank you for raising this question. I completely agree with you—without having read the cited reference, it is indeed difficult to understand what the "inverted S-shaped" relationship specifically refers to.

To improve readability, we have added an explanation of the "inverted S-shaped" relationship. The corresponding revision has been made in lines 254–258 of the main text, and the changes are marked in red. The revised content is as follows:

“The “inverted S-shaped” curve reflects the dynamic relationship between historical population size and deforestation. In the early stages, when the population is relatively small, forest resources are plentiful and the rate of deforestation remains slow. As the population grows, deforestation accelerates rapidly, resulting in a significant loss of forest cover. Eventually, despite the population continuing to increase, the scarcity of remaining forests causes the rate of deforestation to slow down. ”

Point 10. L243: cite the data used.

Response: Thank you for this comment. Revised (Lines 275–277).

Point 11. L270: Fig 3. The whole study is at the provincial level, why do you use gridded data here in the map? What data are they? What criteria did you use to separate west vs. east of China, or to draw the “forest-grassland boundary”? Over 1000 years, did this boundary move at all?

Response: Thank you for this comment.

First, the historical land-use data used in this study is a composite of multiple datasets covering three main categories: cropland, forest, and grassland. Taking into account factors such as spatial-temporal resolution and data operability, we chose the provincial level as the basic unit of calculation.

Figure 3 illustrates the historical land-use change transition rules. Here, we use two gridded maps of forest and grassland data to better convey the information in spatial form. These maps help to visually distinguish forest-dominated and grassland-dominated regions. The two maps are derived from: *He, F., Yang, F., and Wang, Y., 2025. Reconstructing forest and grassland cover changes in China over the past millennium. Science China Earth Sciences, 68(1): 94–110.* They represent the spatial distribution of forests and grasslands in AD 1000 at a 10 km resolution.

The basis for dividing China into western and eastern regions follows: *Su, D.X. The regional distribution and productivity structure of the Chinese grassland resources. Acta Agrestia Sinica, 1994, 2: 71–77.* This study was primarily used to distinguish grassland types, dividing the country into regions primarily comprising the northern temperate zone and the Tibetan Plateau in western China, and nonzonal secondary grasslands in eastern China. Later, the following two studies built upon this division and further classified the "northern temperate zone and the Tibetan Plateau in western China" as zonal grasslands, defining it as the grassland-dominated western region, while the eastern part was historically forest-dominated: *Yang, F., He, F., and Li, S., 2020. Spatially explicit reconstruction of anthropogenic grassland cover change in China from 1700 to 2000. Land, 9(8): 270. He, F., Yang, F., and Wang, Y., 2025. Reconstructing forest and grassland cover changes in China over the past millennium. Science China Earth Sciences, 68(1): 94–110.*

This is the origin of the regional division used in this study.

Finally, we acknowledge that this regional division does not represent a strict boundary. As you rightly pointed out in your comments, the boundary between forests and grasslands may have shifted over the past millennium. However, both our study and the aforementioned literature use this broad division to determine whether a given provincial unit was generally forest-dominated or grassland-dominated. Therefore, even though the boundary may have changed over time, the impact on determining provincial-level affiliation is minimal.

The above explains the details of the data we used, as well as all the background we could think of in response to your comments. We hope this clarifies your concerns. If you have any further questions, we would be happy to provide additional explanation and make further revisions in the next round of responses. Once again, thank you for your thoughtful and constructive comments, which have been instrumental in improving the academic quality of our manuscript.

Point 12. L290: the whole argument about shifting ag. in China is not strongly supported. This happens in Africa and S. America, but it is not as common in China. What does recent remote sensing suggest? It would be more convincing to show some direct evidence than simply claim "…has been recorded extensively in Chinese historical documents."

Response: Thank you for this comment.

Shifting agriculture is an ancient form of agricultural production that was historically widespread. Today, it is mainly found in lowland and hilly areas of tropical rainforest regions, such as those mentioned by the reviewer—Africa and South America. In China, however, this form of cultivation has virtually disappeared since the founding of the People's Republic, as it is a highly extensive and inefficient mode of production. Currently, we have not found any studies that detect this type of agriculture in China using remote sensing data. Therefore, from a data perspective, it is difficult to obtain empirical support for its presence today.

However, from a different angle, because shifting agriculture is such an old production method, if we extend the timeline to several hundred or even a thousand years and broaden the source materials to include historical documents and related scholarly works, we can easily find references to shifting agriculture. In China, it is known as "slash-and-burn" farming. There are numerous historical records about it, although, to our knowledge, no studies besides our own provide detailed quantitative estimates of its extent.

Shifting agriculture is frequently mentioned in historical records and is closely tied to key historical events. Since the mid-Qing Dynasty, the implementation of the "head tax into land tax" (摊丁入亩) policy by the Qing government greatly encouraged population growth. Many scholars describe this as a population explosion. During this period, many displaced people—often referred to as "shelter people" (棚民)—were forced by economic hardship to migrate into previously undeveloped mountainous areas to clear land. In the process, large areas of forest were destroyed, but in fact, very little of this land was converted into permanent farmland. Most of it was temporary cultivation.

Based on this historical background and the records, combined with the reconstructed forest and cropland datasets used in our study, we quantified the area of forest converted to other land. The trend of this change corresponds closely to the historical timeline of "shelter people" expanding into mountainous areas. Therefore, in Figure 5b, we present this data and infer that the primary land-use process responsible was shifting agriculture.

Point 13. Fig. 4-5, did you compare the LUC data with other sources, like LUH2, to examine the differences and causes?

Response: Thank you for this comment.

In Figures 4 and 5, we did not compare our reconstruction results with global datasets such as LUH2, primarily for the following reasons:

To our knowledge, LUH2's long-term historical land-use data largely derives from the HYDE dataset. HYDE is a globally recognized land-use dataset that spans the entire Holocene and includes the historical period covered in our study for China.

Given its widespread application, scholars have long conducted studies to assess the reliability of HYDE data in China. For example:

For cropland in Northeast China over the past 300 years:

Li, B., Fang, X., Ye, Y., & Zhang, X., 2010. Regional accuracy assessment of global land-use datasets: A case study of Northeast China. Science China Earth Sciences, 40(08): 1048–1059.

For traditional agricultural regions:

He, F.N., Li, S.C., Zhang, X.Z., Ge, Q.S., & Dai, J.H., 2013. Comparisons of cropland area from multiple datasets over the past 300 years in the traditional cultivated region of China. Journal of Geographical Sciences, 23(6): 978–990.

For cropland across China over the past millennium:

Zhao, C., He, F., Yang, F., & Li, S., 2022. Uncertainties of global historical land use scenarios in past-millennium cropland reconstruction in China. Quaternary International, 641(20): 87–96.

There are also regional evaluations:

Qinghai–Tibet Plateau:

Li, S.C., He, F.N., Zhang, X.Z., & Zhou, T.Y., 2019. Evaluation of global historical land use scenarios based on regional datasets on the Qinghai–Tibet Area. Science of the Total Environment, 657: 1615–1628.

Xinjiang:

Li, M., He, F., Zhao, C., & Yang, F., 2022. Evaluation of global historical cropland datasets with regional historical evidence and remotely sensed satellite data *from the Xinjiang Area of China. Remote Sensing, 14(17): 4226.*

There are also evaluations of global dataset accuracy for forest and grassland in China:

For forest:

Yang, F., He, F.N., Li, M.J., & Li, S.C., 2020. Evaluating the reliability of global historical land use scenarios for forest data in China. Journal of Geographical Sciences, 30(7): 1083–1094.

For pasture:

He, F., Li, S.C., Yang, F., & Li, M.J., 2018. Evaluating the accuracy of Chinese pasture data in global historical land use datasets. Science China Earth Sciences, 61(11): 1685–1696.

Overall, extensive research has already been conducted to evaluate global datasets such as HYDE, as well as others like PJ, KK10, and SAGE, with a focus on the Chinese region. In Section 2.3.2, "Reliability assessment of long-term land-use change data," we briefly summarize and cite key literature related to the evaluation of global datasets for cropland, forest, and grassland in China, for the benefit of reviewers and readers.

In light of the substantial body of existing work, we decided not to include a direct comparison with global datasets in this study.

Point 14. Fig. 5: please clarify the meaning of secondary axis. In (a), does the y-axis suggest "changes" or absolute area? Same for (b), absolute or relative area? For (c) and (d), what does the pie suggest, 1000-yr cumulative or annual?? Please be more specific.

Response: Thank you for this comment. Revised.

In lines 374–378, we have added new statements to further clarify what the y-axes in panels (a) and (b) represent and their units. We have also clearly explained the meaning of the pie charts in panels (c) and (d). The revisions are marked in red font.

"(a) Cropland, forest, and grassland areas (absolute values), in units of 106 hectares. (b) Proportions of four land-use types in each period, with all remaining terrestrial cover—excluding the reconstructed cropland, forest, and grassland—classified as other land. (c) Cumulative carbon emissions from land-use changes across different carbon pools. (d) Cumulative carbon emissions from different land-use transitions. In (c) and (d), the two pie charts represent the shares of different carbon pools and land-use transitions in the cumulative carbon emissions over the millennium, respectively.”

Point 15. Fig. 6: Does the negative biomass value show carbon sink? Specify in the caption.

Response: Thank you for this comment. Revised. (Line 408)

Point 16. L435: Table3, this table is a summary not “comparison. These estimates cover different time period, so the emissions would be different. No surprise here. Could you compare them across the same or similar time, and include results from this study?

Response: Thank you for this comment.

The studies listed in Table 3 have differences in time periods, and some of the differences in their results are due to this. Therefore, as described in lines 427-428 of this manuscript, they are strictly speaking not comparable.

Given that the data from the studies listed in Table 3 are not open access, we cannot modify their data to obtain consistent time periods across all these studies. However, our data represents annual carbon budgets, and we extracted overlapping time periods from both this study and the existing studies. We compared our results (the last column of Table 3) with those from the existing studies for the same time periods and analyzed the reasons for the differences in the manuscript.

Since Table 3 is quite long, with 7 columns, and our results are in the last column, you may not have noticed this column. The new Table 3 is the result of revisions made in response to the suggestions of another reviewer.

Table 3. Comparison of existing long-term carbon emission estimation results caused by land-use change in China

Region	Land use type	Method	Time period	Previous study (Pg C)	Reference	This study (Pg C)
China	Cropland, Forest, Grassland	Bookkeeping model (Early version)	1700–1980	9.05	Yang et al. (2023)	15.17
China	Cropland	Bookkeeping model (Early version)	1661–1980	3.78	Yang et al. (2019)	16.13
China	Cropland, Forest	Bookkeeping model (Early version)	1700–1949	6.18	Ge et al. (2008)	11.87
Northeast China (Heilongjiang, Jilin, and Liaoning)	Cropland	Bookkeeping model (Early version)	1680–1980	1.45	Li et al. (2014)	3.33
Global	Cropland, Forest, Grassland, Other land	Bookkeeping model (Latest version)	1850–2019	7.36	Houghton and Castanho (2023)	7.72
China	Cropland, Forest	Land ecosystem model	1900–1980	6.90	Yu et al. (2022)	7.07
China	Cropland, Forest	Land ecosystem model	1980–2019	8.90	Yu et al. (2022)	2.25
China	Cropland, Forest, Grassland, Other land	Bookkeeping model (Latest version)	1000-2019	19.61	This study	

Point 17. L476: Is this required? It seems odd with a data availability statement in the middle.

Response: Thank you for this comment.

Since ESSD is primarily a data-focused journal and we are submitting a data description article, according to the journal's template, the Data Availability section is required, and the data must be shared on an open access platform.

Point 18. Appendix A and B: is the information in these tables used in this study? Or do they simply support previous work on LUC data.

Response: Thank you for this comment.

The information in Appendices A and B is used in this study and serves as important supporting data for the results presented in the manuscript. Due to limitations in length, structure, and logical flow, we placed this content in the appendices.

Specifically, Table A1 provides detailed sources for the second and third national land survey bulletins; Table B1 lists soil series in China; Table B2 presents the disturbance response curve parameters; Figures B1–B4 show the sample points for soil carbon density.

Thank you again for your thorough and professional feedback on our manuscript. We truly appreciate your time and expertise. We are open to any additional questions or suggestions in the next round of review and are committed to further improving the paper.

Response to Reviewer 2 Comments

Manuscript Title: Annual carbon emissions from land-use change in China from 1000 to 2019

Recommendation: Major Revision

General Comments

This manuscript presents an ambitious reconstruction of carbon emissions from land-use change (LUC) in China over the past millennium. Using a provincial-scale bookkeeping model and extensive historical records, the authors estimate annual LUC emissions from 1000 to 2019, supported by updated carbon density datasets. The work contributes a long-term dataset of carbon fluxes that could support both paleoclimate-carbon research and national greenhouse gas (GHG) accounting.

However, the manuscript falls short in clearly articulating its scientific motivation, ensuring methodological transparency, and validating the results. Of particular concern is the assumption that vegetation and soil carbon densities remain constant over 1000 years, which critically weakens the interpretability of the results. In addition, the complete absence of quantitative uncertainty analysis and comparison with existing datasets limits the credibility and broader applicability of the findings.

I recommend major revision to address the following concerns.

Response: Thank you very much for taking the time to review our manuscript. We appreciate your recognition of our topic and work.

In response to the questions and concerns you raised, we have made substantial revisions to the manuscript. These include adding more detailed descriptions of our methodology to enhance its transparency and quantifying the estimation uncertainties using Monte Carlo simulations. Please find our point-by-point responses below. All changes in the manuscript have been marked in red font.

Thank you once again for your valuable feedback.

Major Comments

Point 1. The scientific rationale, challenges, and innovation of a millennial-scale reconstruction are insufficiently articulated

While reconstructing LUC-related carbon emissions since AD 1000 is conceptually valuable, the manuscript does not sufficiently explain:

- Why this timescale is necessary for understanding anthropogenic impacts on the carbon cycle;
- What methodological or conceptual challenges exist in performing such long-term reconstructions;
- How this study specifically overcomes those challenges or improves upon prior work.
- The novelty of the study must be made more explicit. For example:
- How does this reconstruction differ from studies that begin in 1700 or 1850?
- What new historical sources, spatial refinements, or analytical methods are introduced?

Recommendation: Include a comparative table summarizing key differences between this study and prior LUC carbon emission reconstructions (e.g., in time span, resolution, input data, model approach, and validation).

Response: Thank you for this comment. We have added substantial content to the Introduction section to elaborate on why we conducted a study over such a long period, why the past 1000 years are of particular importance to China, and the implications of this work for China and other nations. For details, please see lines 70-84 of the main text, which are excerpted as follows:

"China has a vast territory and a long history of land use, making it an important contributor to global terrestrial carbon dynamics caused by anthropogenic land-use change and land management. Although most global and regional studies on land-use change focus on the post-industrial era or the past three centuries, China's intensive and extensive land-use activities date back at least a millennium, thus representing a unique historical trajectory (He et al., 2025, 2023). From approximately AD 1000 (coinciding with the Northern Song Dynasty), ecological degradation in China showed a marked rise. This degradation was manifested through multiple pathways: accelerated erosion on the Loess Plateau, recurrent floods in the lower Yellow River Basin, large-scale lake siltation and disappearance in northern China, and progressive soil erosion coupled with natural vegetation loss in the southern hill regions (Wu et al., 2020; Chen et al., 2012). Such millennial-scale land-use transitions would have generated substantial carbon emissions, particularly from deforestation. However, the relatively stable pre-industrial global CO_2 concentrations likely obscured these regionally significant anthropogenic carbon fluxes because localized emissions in areas such as China could have been offset by concurrent carbon sinks elsewhere. Additionally, the full trajectory or specific stages of historical land-use change in China can serve as a "historical analogue" for other developing countries. For many countries and regions, systematically revealing the processes and mechanisms of land-use change and associated carbon emissions—driven by long-term population growth and policy shifts—can help overcome the limitations associated with a lack historical records and reliance on static assumptions."

In our updated Table 3, building upon the original comparison with previous studies, we have further clarified key information such as the time span, input land-use types, and model employed, in order to highlight the critical differences between the various studies. For details, please see lines 499-501 of the main text, which the updated table is excerpted below:

Table 3. Comparison of existing long-term carbon emission estimation results caused by land-use change in China

Region	Land use type	Method	Time period	Previous study (Pg C)	Reference	This study (Pg C)
China	Cropland, Forest, Grassland	Bookkeeping model (Early version)	1700–1980	9.05	Yang et al. (2023)	15.17
China	Cropland	Bookkeeping model (Early version)	1661–1980	3.78	Yang et al. (2019)	16.13
China	Cropland, Forest	Bookkeeping model	1700–1949	6.18	Ge et al. (2008)	11.87

		(Early version)				
Northeast China (Heilongjiang, Jilin, and Liaoning)	Cropland	Bookkeeping model (Early version)	1680–1980	1.45	Li et al. (2014)	3.33
Global	Cropland, Forest, Grassland, Other land	Bookkeeping model (Latest version)	1850–2019	7.36	Houghton and Castanho (2023)	7.72
China	Cropland, Forest	Land ecosystem model	1900–1980	6.90	Yu et al. (2022)	7.07
China	Cropland, Forest	Land ecosystem model	1980–2019	8.90	Yu et al. (2022)	2.25
China	Cropland, Forest, Grassland, Other land	Bookkeeping model (Latest version)	1000-2019	19.61	This study	

Note: Bookkeeping model (Early version) refers to the initial model developed by Houghton and Hackler (2003). Bookkeeping model (Latest version) refers to the most recently updated model by Houghton and Castanho (2023).

Point 2. The assumption of static carbon densities undermines the long-term credibility of the reconstruction

A central concern lies in the assumption that vegetation and soil carbon densities remain constant over the entire 1000-year period. While this may be a necessary simplification given limited historical data, it significantly weakens the scientific credibility of the estimated carbon fluxes—especially for earlier centuries.

Carbon densities are not time-invariant: they are influenced by changes in climate, atmospheric CO_2, ecosystem succession, species composition, and land-use intensity. Assuming present-day carbon densities for all historical periods' risks introducing systemic bias in the emission estimates, particularly during major climatic or socio-ecological transitions (e.g., the Little Ice Age, or the Qing Dynasty agricultural expansion).

This assumption is particularly problematic because the technical challenge—and scientific value—of millennial-scale carbon accounting lies precisely in addressing such temporal variability. If a key driver like carbon density is held static, the study risks becoming an arithmetic exercise rather than a meaningful reconstruction, and its findings may not substantially differ from earlier studies based on heuristic extrapolation.

Recommendation:

- Clearly state which carbon density datasets are used, and how they are applied across the time domain;
- Acknowledge the limitations of assuming static carbon densities, and discuss the potential magnitude and direction of bias this may introduce;
- Propose a pathway for future work, such as incorporating carbon density outputs from process-based vegetation models (e.g., DGVMs) or paleoecologically reconstructions;
- Emphasize that confronting this assumption is essential for enhancing the interpretive value and novelty of the study.

Response: I strongly agree with the issue you've raised.

The bookkeeping model used in this study is primarily driven by land-use change data and utilizes observed vegetation and soil carbon density data and specific disturbance response curves for each land-use transition type. As this method excludes the influence of unchanged land-use types and environmental changes, such as carbon dioxide concentrations and climate change, it quantifies direct anthropogenic fluxes and ignores carbon fluxes driven by environmental changes (Dorgeist et al., 2024; Houghton and Castanho, 2023). However, at the same time, as you mentioned, it overlooks the long-term impacts of environmental changes (e.g., climate, CO_2 concentration) on carbon stocks.

In our discussion section, we have added a discussion on the limitations of static carbon densities and pathways for future improvement in lines 565-573. Here is the excerpt:

"Additionally, the spatiotemporal variability of basic carbon density values can influence the accuracy of the estimates. In this study, carbon density is addressed using a "present-day-for-past" substitution method. Although modern soil carbon densities were moderately adjusted by incorporating a large-scale soil sampling survey dataset from the post-1949 period in China, pre-industrial carbon stocks likely varied due to shifts in atmospheric CO_2 concentrations, climate fluctuations, ecological succession, and human land management. Vegetation and soil carbon densities were not static over the past millennium. Therefore, using static values to represent historical carbon densities may fail to capture temporal dynamics, thereby introducing uncertainties. Potential biases include overestimating human contributions if climate-driven increases in carbon density are ignored and overestimating modern carbon uptake if long-term baseline declines in carbon stocks are not included. Future studies should explore coupling DGVMs (e.g., LPJ or ORCHIDEE) to simulate combined impacts of historical climate, CO_2 levels, and human activities on carbon density."

Point 3. Modern-era results lack validation and comparison with existing datasets

The study spans from 1000 to 2019, but observational and model-constrained datasets are available primarily for the post-1950 period. Yet the manuscript does not compare its estimates to:

- National or global LUC carbon emission inventories (e.g., FAO, Houghton, LUH2);
- Remote sensing-based datasets of forest loss or biomass change;
- Process-based models such as DGVMs or spatially explicit bookkeeping models (e.g., BLUE).

These comparisons are essential for establishing the reliability of the methodology and providing a reference point for earlier trends.

Recommendation: Include a table comparing national and/or provincial LUC emissions from this study with at least 3–4 widely used datasets over overlapping time periods, accompanied by discussion on differences and their likely causes.

Response: Thank you for this comment.

In Figure 10, we present a comparison between the reconstruction results of this study and those of other relevant studies, particularly for the period since 1950 (see line 523 in the main text for details). Furthermore, we have provided a detailed discussion on the discrepancies among different research findings and their primary causes, as detailed in lines 510-548 and excerpted below.

"The estimates from the other three bookkeeping models aligned more closely with the trends in the DGVM estimates, which were markedly different from our estimations. This discrepancy primarily stems from two key aspects. First, DGVM estimates often account for the "loss of additional sink capacity". This concept refers to the diminished carbon absorption that occurs when the land-use type of a parcel of land that could have absorbed more carbon dioxide under current environmental conditions if left in its original natural state (e.g., as a forest) is altered by human activities (e.g., conversion to cropland), thereby reducing its actual carbon dioxide uptake. This "reduction in absorbed amount" constitutes the loss of additional sink capacity. Gasser et al. (2020) revealed that the inclusion or exclusion of loss of additional sink capacity leads to significant differences in estimated values. Second, disparities in land-use change forcing data represent another significant factor contributing to divergent estimates among different models. DGVM estimates are typically driven by long-term global land-use datasets, such as LUH2 (Obermeier et al., 2024; Friedlingstein et al., 2019; Hansis et al., 2015). Thus, these models that differ due to the inclusion of loss of additional sink capacity and the use of varying land-use change data tend to significantly overestimate the carbon emission flux from land-use changes relative to the results of this study."

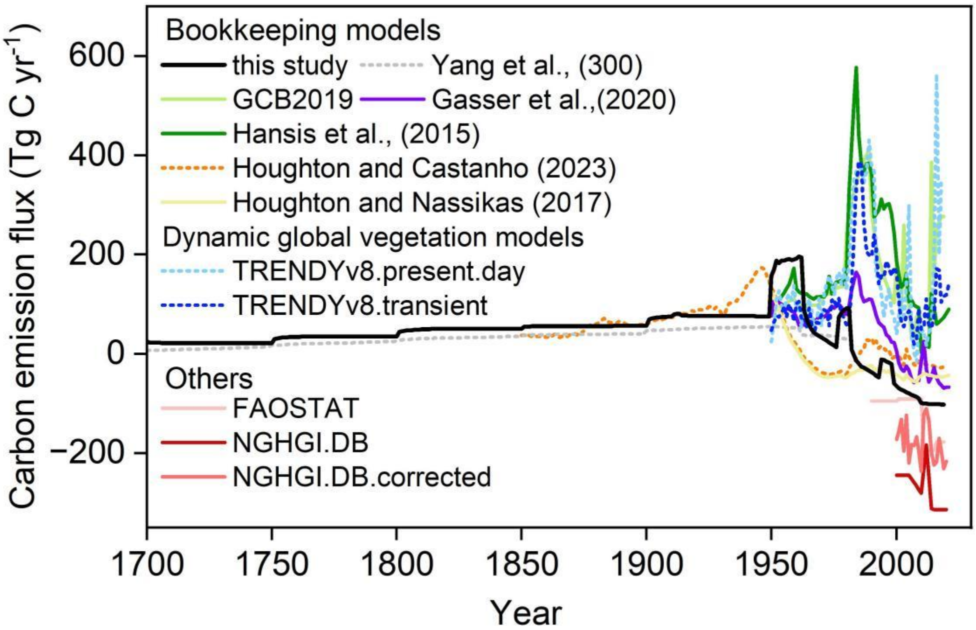

Figure 10. Chinese historical land-use change-induced carbon emission flux estimated by different methods.

"Additionally, the estimates from this study differed considerably from national report-based data (e.g., NGHGIs and FAOSTAT) (Fig. 10) (Obermeier et al., 2024). The core difference between NGHGIs and bookkeeping models in land-use change carbon flux estimation lies in the carbon accounting boundary, especially regarding the attribution of indirect fluxes on managed land (Gidden et al., 2023; He et al., 2024). NGHGIs tend to consider all carbon fluxes on managed land (including both direct fluxes and indirect fluxes triggered by environmental changes) as anthropogenic contributions. In contrast, bookkeeping models primarily account for direct fluxes generated by direct human activities but exclude indirect fluxes, which are considered natural ecosystem responses, from anthropogenic inventories of land-use change. The fact that national reports specifically account for afforestation and ecological restoration projects with high carbon removal potential might also influence the results. The most direct example is the similarity between our estimated carbon emissions (1900–1980) and the results of Yu et al. (2022) (Table 3) because of the lack of significant or widespread land management or engineering projects in China during this period. However, the estimates for 1980–2019 differed greatly because land management practices during this period had a substantial impact. As revealed by Yue et al. (2024), land management has played a crucial role in China's land-carbon balance since 1980."

Point 4. Absence of quantitative uncertainty analysis limits credibility

Section 4.3 is labeled "Uncertainty Analysis" but provides only qualitative reflections on limitations. This is insufficient given the range of assumptions, spatial heterogeneity, and sparse data for earlier centuries.

Recommendation:

- Include a quantitative uncertainty analysis (e.g., via Monte Carlo simulations or scenario analysis);
- Report confidence intervals or uncertainty bounds for cumulative and decadal emissions;
- Indicate how uncertainty varies across time, especially between well-documented (post-1950) and poorly constrained (pre-1700) periods.

Response: Thank you for this comment. In response to your comments, we have estimated the uncertainty associated with our carbon emission results using Monte Carlo simulations. The details are provided in lines 351-362 and 540-548. An excerpt is provided below:

2.3.4 Uncertainty assessment

To evaluate the uncertainty in estimating carbon emission fluxes, this study employed Monte Carlo simulations with 1000 iterations. The uncertainty primarily stems from two key parameters: carbon density and land-use change area. For the carbon densities in the forest (aboveground, belowground, and soil) and grassland (aboveground, belowground, and soil) components, the mean and standard deviation were calculated based on input sample data. During the simulations, values for these densities were randomly sampled from normal distributions parameterized based on these statistics measures. Regarding the land-use change area, the original input value for the annual conversion area of each land-use type served as the mean for its sampling distribution, with the standard deviation set to 10% of this mean. Values were then randomly sampled from a normal distribution defined by these parameters in each iteration. Subsequently, in every iteration, the annual carbon emission flux was re-estimated using the parameters sampled in that specific iteration. After aggregating the results from all iterations, the minimum and maximum simulated carbon emission flux values for each year were used to define the uncertainty interval for that year's estimates.

4.3 Uncertainty analysis

This study employed Monte Carlo simulations (1000 iterations) to systematically assess the uncertainty in annual carbon emission flux estimates (Fig.11). The results revealed that the average annual uncertainty interval, which was derived from the maximum and minimum simulated carbon emissions, was 18.75 Tg C. This interval exhibited significant interannual variation, ranging from a minimum of 3.77 Tg C to a maximum of 143.67 Tg C. Such variation indicates that the uncertainty in the estimation results increased in years characterized by substantial fluctuations in land-use change data. Overall, the Monte Carlo simulations effectively highlighted the impact of parameter uncertainty on carbon emission estimates and provided a quantitative basis for evaluating the credibility of the carbon flux results. To further constrain parameter variability, future efforts should focus on improving the resolution of measured carbon density data and the reliability of land-use data."

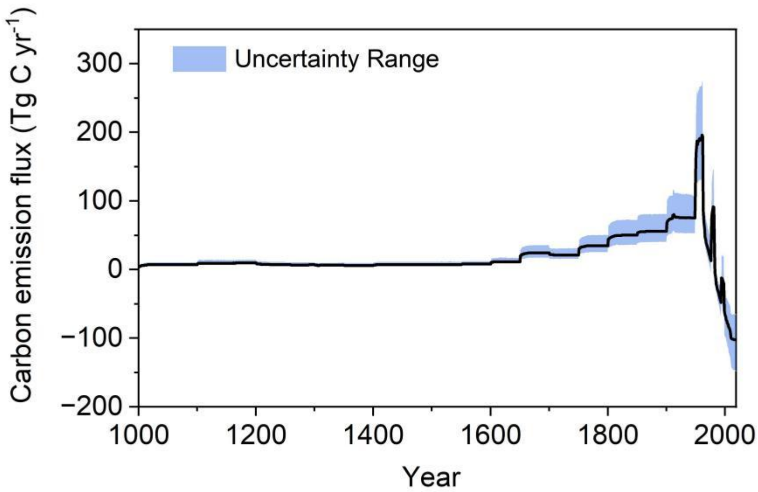

Figure 11. Uncertainty in annual carbon emissions from land use change

Minor Comments

Point 5. Clarify the bookkeeping framework

Indicate whether this is a "statistical bookkeeping model" or incorporates spatially explicit components to distinguish it from models such as BLUE or OSCAR.

Response: Thank you for this comment. Revised.

Per your suggestion, we have now clarified in the Methods section that this is a statistical model (see lines 192-197 of the manuscript, highlighted in red). The excerpt is as follows:

"The bookkeeping method (a statistical model) proposed by Houghton and Castanho (2023) was employed to estimate the annual carbon emissions caused by land-use changes in China from 1000 to 2019. Due to data limitations, long-term historical land-use reconstructions in China are primarily constrained to land-use "states" (e.g., total cropland or forest area at national/provincial levels for specific years) rather than spatially explicit land-use transitions. This characteristic, combined with the provincial-level spatial resolution of our data, makes such reconstructions inherently compatible with the bookkeeping model adopted here (Houghton and Castanho, 2023)."

Point 6. Add a conceptual model diagram

A schematic showing the flow from land-use data → transition → response curve → carbon flux would clarify the modeling approach.

Response: Thank you for this comment. Revised.

We thank you for this valuable suggestion. Accordingly, we have constructed Figure 2 (Framework for calculating annual carbon emissions based on the bookkeeping model). This has been added to the revised manuscript, with the details provided on lines 182-183 and 188-189 (highlighted in red for clarity).

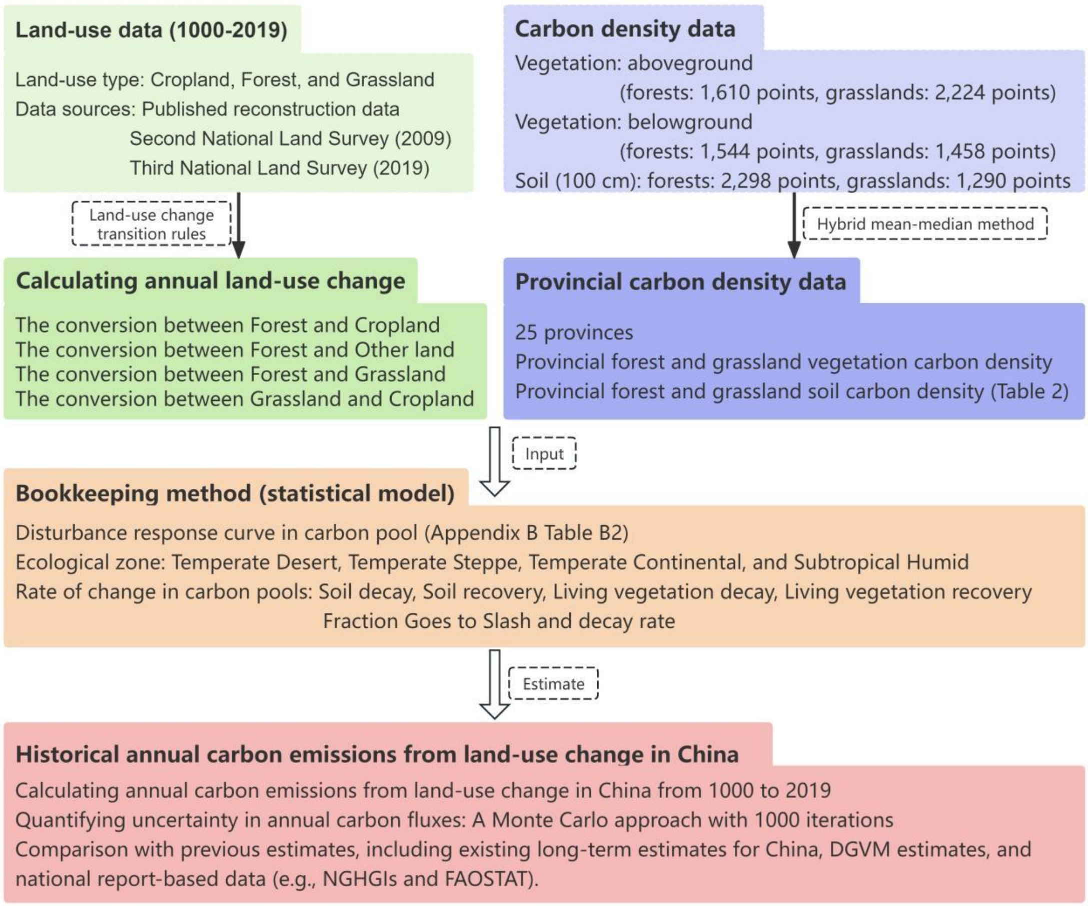

Figure 2. Framework for calculating annual carbon emissions based on the bookkeeping model.

Point 7. Improve Table 2

Include the number of observations or sample density for each province to help readers assess data quality.

Response: Thank you for this comment. Revised.

As suggested, we added sample sizes for forest and grassland carbon density (both vegetation and soil) for each province to Table 2. The changes are highlighted in red in lines 179-180.

Table 2. Provincial vegetation and soil carbon density data

Province/region	Forest (Mg/ha)		Grassland (Mg/ha)	
	SOCD	VCD	SOCD	VCD
Chuan-Yu	98.83 (n=132)	55.96 (n=159)	143.09 (n=50)	1.25 (n=142)
Inner Mongolia	69.38 (n=179)	41.60 (n=263)	88.79 (n=119)	5.77 (n=416)
Liaoning	91.13 (n=70)	44.74 (n=43)	77.71 (n=35)	3.32 (n=25)
Jilin	95.09 (n=57)	73.85 (n=39)	67.09 (n=30)	3.06 (n=24)
Heilongjiang	145.45 (n=91)	64.63 (n=114)	93.58 (n=28)	2.98 (n=22)
Gan-Ning	99.44 (n=88)	36.80 (n=57)	54.66 (n=236)	3.80 (n=159)
Qinghai	75.87 (n=20)	30.54 (n=36)	108.60 (n=249)	6.45 (n=385)
Xinjiang	64.32 (n=22)	25.59 (n=42)	93.97 (n=119)	4.09 (n=91)
Xizang	129.33 (n=35)	82.43 (n=20)	58.89 (n=167)	4.20 (n=291)
Jing-Jin-Ji	75.39 (n=104)	43.83 (n=117)	88.32 (n=53)	7.61 (n=19)
Shanxi	59.98 (n=65)	40.63 (n=66)	56.13 (n=115)	8.77 (n=71)
Shaanxi	74.29 (n=174)	29.78 (n=101)	64.75 (n=110)	4.03 (n=45)
Shandong	60.42 (n=30)	42.29 (n=26)	/	/
Henan	59.03 (n=17)	42.41 (n=24)	/	/
Anhui	86.90 (n=44)	63.06 (n=57)	/	/
Hu-Ning	91.79 (n=31)	37.63 (n=27)	/	/
Hunan	92.60 (n=174)	51.94 (n=42)	/	/
Hubei	139.57 (n=63)	48.00 (n=20)	/	/
Jiangxi	93.29 (n=162)	50.81 (n=44)	/	/
Zhejiang	115.13 (n=69)	54.14 (n=35)	/	/
Fujian	117.71 (n=114)	58.80 (n=72)	/	/
Yue-Qiong	111.36 (n=233)	37.33 (n=92)	/	/
Guangxi	108.26 (n=156)	55.87 (n=105)	99.32 (n=17)	/
Yunnan	105.84 (n=110)	76.26 (n=67)	100.52 (n=14)	/
Guizhou	129.37 (n=64)	50.31 (n=29)	284.18 (n=35)	/

SOCD refers to soil organic carbon density, VCD refers to vegetation carbon density.

Point 8. Clarify carbon density preprocessing

Indicate whether carbon density values were standardized (e.g., by reference depth) and whether outliers were removed.

Response: Thank you.

The selection of carbon density data points and the calculation of provincial-level carbon densities were subject to specific filtering and processing. Notably, for soil carbon density, data points with a profile depth of at least 100 cm were chosen, and their soil carbon density was calculated for a 100 cm depth (detailed in manuscript lines 162-164).

In general, the data for above-ground, below-ground, and soil carbon densities for each province were normally distributed (see Appendix Figs. B2–B4). The arithmetic mean was used to calculate the provincial-level average carbon density. For provinces with exceptionally high or low values, the median was used to represent the central tendency and to minimize the influence of outliers (see lines 174-176).

Point 9. Enhance regional time-series presentation (e.g., Fig. 7)

Add temporal trends for individual regions, not just cumulative bar plots.

Response: Thank you for this comment.

Based on the comments and suggestions of the three reviewers, we have added a conceptual model diagram and an uncertainty analysis chart based on Monte Carlo simulations to the original nine figures in the main text. There are now a total of 11 figures in the main text. Considering the large number of figures, we have decided to place the chart showing the trend of carbon emissions over time for each province in Appendix C as Figure C1. This will make it easier for reviewers and readers to understand the details of carbon emission changes in each province.

Appendix C

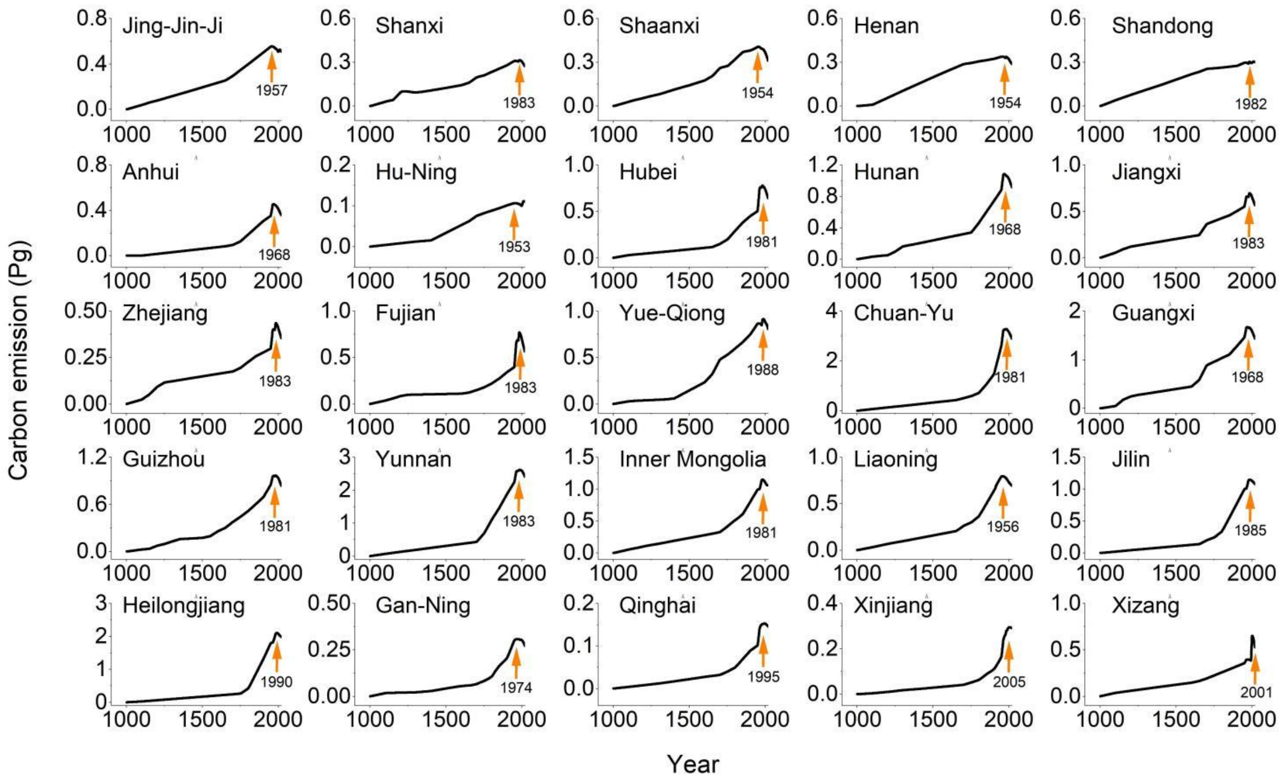

Figure C1. Cumulative carbon emissions from land-use changes at the provincial level. Arrows indicate the turning points from carbon sources to carbon sinks, with numbers representing the corresponding years of the turning points.

Point 10. Clarify the role of Appendices A and B

State whether the sources listed in the appendices were used directly in this study or referenced for historical context only.

Response: Thank you for this comment.

The information in Appendices A and B is used in this study and serves as important supporting data for the results presented in the manuscript. Due to limitations in length, structure, and logical flow, we placed this content in the appendices.

Specifically, Table A1 provides detailed sources for the second and third national land survey bulletins; Table B1 lists soil series in China; Table B2 presents the disturbance response curve parameters; Figures B1–B4 show the sample points for soil carbon density.

Point 11. Ensure consistent terminology

Maintain consistent use of terms like “carbon sink” vs. “carbon sequestration.”

Response: Thank you for this comment. Revised.

Thank you for your suggestion. To avoid unnecessary ambiguity, we have carefully reviewed the entire manuscript and replaced all instances of the word “sequestration.” For details, please see lines 440-442, 512, and 571, which are marked in red font.

Point 12. Improve figure quality

Enhance the resolution of Figures 5–8 and define all abbreviations in figure captions (e.g., “Yue-Qiong”).

Response: Thank you. Revised.

We apologize that the figures were not clear enough during your review, which may have been due to low initial resolution or issues during the Word-to-PDF conversion process. In this revision, we have re-inserted higher-resolution figures into the Word manuscript. However, since the conversion to PDF is handled by the editorial office, we do not have control over this step and are unsure to what extent the conversion process might affect the final image resolution.

If the figures are still not clear enough during your review, we ask for your understanding. Should our manuscript be accepted, we will upload high-resolution image files separately to ensure the clarity of the figures in the final publication. Thank you again for your understanding.

Additionally, we have added definitions for all abbreviations in the captions of the relevant figures. For details, please see Figure 9 and lines 448-450.

Point 13. Refine the title for clarity

Consider including terms such as “provincial reconstruction” or “bookkeeping-based estimate” to better reflect the methodological approach.

Response: Thank you for this comment.

We, the authors, have had extensive discussions regarding your suggestion about revising the title. We agree that the original title’s strengths are its conciseness, clarity, and broad appeal, while your proposed change would highlight the methodological and data-driven contributions, which would help attract a more specific audience. This is indeed a trade-off between “conciseness and clarity” and “richness of information.”

We seriously considered adding these terms to the title. However, after our discussions, we still lean towards keeping the original title for two main reasons. First, we believe the current concise title—“Annual carbon emissions from land-use change in China from 1000 to 2019”—most effectively communicates the core findings to a broader audience, including policymakers and scientists from other disciplines. Second, we consider the primary contribution of this study to be the millennium-scale emissions dataset itself, and a title focused on the results best reflects this contribution.

To ensure that our methods and data characteristics are immediately apparent to readers, we have revised the abstract and methods section to explicitly highlight the key terms "provincial reconstruction" and “bookkeeping-based estimate.”

Thank you again for your valuable guidance.

In summary, thank you once again for providing so many valuable comments and suggestions on our manuscript. We have fully absorbed them and have made revisions to the best of our ability. Your feedback has led us to re-examine the shortcomings in the structure and expression of the original manuscript, significantly improving its readability and scientific rigor.

We are very grateful for this valuable opportunity to engage with you. There may still be areas in the manuscript that are not entirely satisfactory, and we welcome you to point them out in the next round of review. We will strive to better understand your comments and suggestions and work to further improve the manuscript.

Thank you again!

Response to Reviewer 3 Comments

This manuscript presents a millennial-scale reconstruction of carbon emissions from land-use change in China using a bookkeeping model approach. While the study addresses an important research gap and provides valuable historical context for understanding China's carbon budget, there are several major concerns that must be addressed before this work is suitable for publication.

Response: Thank you very much for taking the time to review our manuscript and for your positive and encouraging comments. We have carefully considered the four main areas for revision or questions you raised. We have made detailed modifications and responses to each opinion or suggestion, and these changes have been marked in red font in the main text. Thank you again for your hard work; your comments have significantly improved the scientific quality of our manuscript.

Point 1. The conversion rules in Figure 3 appear somewhat arbitrary. I recommend testing the uncertainty in your transition matrix calculations. While your rule-based priority system is clear, how would results differ if you used an area-weighted approach instead? For example, allocating transitions proportionally based on the relative magnitude of area changes between different biomes rather than using predetermined priorities. This uncertainty analysis would be valuable given the millennium-long timeframe of your study, where even small methodological differences could compound into significant variations in results.

Response: Thank you for this comment. We apologize if our previous explanation of the land-use transition rules in Figure 4 was not detailed enough and caused confusion. We have further clarified this section in the revised manuscript, and these revisions are marked in red font. For details, please see lines 305-326.

Please allow me to briefly explain.

Firstly, the conversion rules are determined based on the attributes of the published data used, which is a prerequisite for establishing the land use transition rules in this study. Specifically, when reconstructing historical grassland data in western China, it reflects the occupation of grassland due to the reclamation of cropland in history. In eastern China, historical grasslands mainly consist of secondary grasslands resulting from the secondary succession of deforested lands. The reconstruction rules for historical grassland data are the basis for formulating grassland-related land use conversion rules in this study.

After the land use transition rules related to grassland were established, whether it was the conversion of forest to cropland or forest to other land, historically, the essence was deforestation for reclamation. After deforestation, if the land could be cultivated for a long period, it was converted to cropland. If it became temporary cropland due to reasons such as loss of fertility, it is defined as other land in this study. According to Table B2 in the appendix, in the bookkeeping model used in this study, the disturbance response curves for the conversion of forest to cropland and forest to other land are identical. Therefore, once the land use conversion rules related to grassland are established, regardless of whether we use our set priorities or other methods (such as area weighting) to handle forest-related land use conversions, the final carbon emission calculation results will not be affected by the specific classification of forest conversion into cropland or other land.

The excerpt is as follows:

"First, the conversion rules were determined based on the attributes of the published data used, which was a prerequisite for establishing the land-use transition rules in this study. The land-use change data revealed the changes in grassland area and their conversion relationships were the most clearly defined. The reconstruction rules for historical grassland data formed the basis of the grassland-related land-use conversion rules in this study. Specifically, when reconstructing historical grassland data in western China, the data reflect the occupation of grassland due to the reclamation of cropland in history (He et al., 2024). Therefore, for western China, where grassland ecosystems dominate, changes in grassland areas primarily reflect the encroachment of croplands, and the conversion between grassland and cropland was determined first based on changes in grassland area (Fig. 4). Second, the reduction in forest area was prioritized for conversion to cropland, followed by conversion to other land. In eastern China, where forest ecosystems are predominant, historical grasslands mainly consisted of secondary grasslands because of the secondary succession of deforested lands (He et al., 2024). Hence, in eastern provinces dominated by forest ecosystems, the conversion between grassland and forest can be similarly determined based on changes in the grassland area. The remaining forest area was then prioritized for conversion to cropland, followed by conversion to other land. Based on these rules, we calculated the annual land-use change rates in China from 1000 to 2019.

Historical conversion of forest to cropland or forest to other land was primarily performed for land reclamation, and if the deforested land supported cultivation over a long period, it was converted to cropland. For cropland that failed to support cultivation due to reasons such as a loss of fertility, it was defined as other land in this study. According to Table B2 in the appendix, in the bookkeeping model used in this study, the disturbance response curves for the conversion of forest to cropland and forest to other land were identical. Therefore, once the land-use conversion rules related to grassland were established, regardless of whether the set priorities or other methods (such as area weighting) were used to handle forest-related land-use conversions, the final carbon emission calculation results were not be affected by the specific classification of forest conversion into cropland or other land."

Point 2. The authors state that "this study updated and improved the land-use change data, carbon density data, and disturbance response curves," but upon careful reading, it appears they did not actually update or improve the disturbance response curves themselves. Rather, they simply adopted the data from Houghton and Castanho (2023) without modification. To avoid misleading readers, I suggest the authors clarify that they utilized the most recently published parameters from the literature rather than implying they developed improvements to the response curve themselves.

Response: Thank you！

I completely agree with your opinion. Yes, we directly used the latest published disturbance-response curve from Houghton and Castanho (2023). Several statements in the original manuscript regarding this curve might have been misleading or ambiguous for readers and reviewers. Therefore, in the revised manuscript, we have amended the relevant descriptions to clarify that we directly used the latest published disturbance-response curve from Houghton and Castanho (2023) without any further modifications. For details, please see lines 25-27, 105-106, 475-476, and 587-590 in the main text, highlighted in red font.

Point 3. I also noticed that the bookkeeping model used in this study does not account for wood harvest pools, which is understandable given that it would require reconstructing additional historical wood harvest data. However, this limitation should be explicitly stated in the methodology section. The authors should clarify this omission and briefly discuss its potential implications for carbon flux estimates, especially since wood harvest can be a significant component of land-use change emissions in forested regions of China.

Response: Yes, I completely agree with your point.

We have clarified this in the methods section of the revised manuscript: Due to data limitations, this accounting does not consider carbon emissions from wood harvest. For details, please see lines 186-187 of the manuscript.

Simultaneously, in the discussion section, lines 574-580 (marked in red font), we re-emphasized that the current accounting does not include wood harvest, as well as the potential impacts arising from the omission of wood harvest. By integrating existing relevant literature, reference values for carbon emissions from wood harvest were provided. The excerpt is as follows:

"We reiterate that the carbon emission accounting method in the present study does not include wood harvesting. Considering that wood harvesting represents a significant historical source of anthropogenic emissions, the absence of these data may lead to a certain degree of underestimation in the corresponding carbon emission fluxes. Fortunately, Houghton and Castanho (2023) estimated China's long-term carbon emissions from wood harvesting and found values of 5 Tg C yr^{-1} for 2011–2020, approximately 20–30 Tg C yr^{-1} around the 1950s, approximately 5–10 Tg C yr^{-1} in the 1900s, and less than 5 Tg C yr^{-1} values before 1900. These estimates can serve as a reference when regional long-term reconstructed data on wood harvesting and their corresponding carbon emission estimates are unavailable."

Point 4. The explanation of differences between NGHGI and bookkeeping estimates should focus on carbon accounting boundaries rather than restoration projects (Gidden et al., 2023, Nature; He et al., 2024, Nature Communications). For DGVMs vs. bookkeeping models, note that DGVMs include the loss of additional sink capacity, leading to higher emission estimates, alongside differences in LUC forcing data (Gasser et al., 2020, Biogeosciences). I suggest the authors provide a more systematic discussion to avoid misleading readers about these differences.

Response: Thank you very much for your comments. Your opinions are accurate and highly valuable, helping us to revise the relevant content in section 4.2 Comparison with previous estimates, strengthen the comparison between different results, and make the relevant explanations more scientific and persuasive. Thank you again.

We have collected and consulted relevant literature and content. Incorporating your suggestions, we have revised this part, detailed in lines 510-538, and marked the changes in red font. We are not entirely certain if our revisions have fully addressed and alleviated your concerns regarding our manuscript. If there are any further questions or if our explanations are not adequate, please raise them in the next round of evaluation. We will further strive to understand your opinions to improve the manuscript. The relevant revisions are excerpted as follows:

"The estimates from the other three bookkeeping models aligned more closely with the trends in the DGVM estimates, which were markedly different from our estimations. This discrepancy primarily stems from two key aspects. First, DGVM estimates often account for the "loss of additional sink capacity". This concept refers to the diminished carbon absorption that occurs when the land-use type of a parcel of land that could have absorbed more carbon dioxide under current environmental conditions if left in its original natural state (e.g., as a forest) is altered by human activities (e.g., conversion to cropland), thereby reducing its actual carbon dioxide uptake. This "reduction in absorbed amount" constitutes the loss of additional sink capacity. Gasser et al. (2020) revealed that the inclusion or exclusion of loss of additional sink capacity leads to significant differences in estimated values. Second, disparities in land-use change forcing data represent another significant factor contributing to divergent estimates among different models. DGVM estimates are typically driven by long-term global land-use datasets, such as LUH2 (Obermeier et al., 2024; Friedlingstein et al., 2019; Hansis et al., 2015). Thus, these models that differ due to the inclusion of loss of additional sink capacity and the use of varying land-use change data tend to significantly overestimate the carbon emission flux from land-use changes relative to the results of this study.

Additionally, the estimates from this study differed considerably from national report-based data (e.g., NGHGIs and FAOSTAT) (Fig. 10) (Obermeier et al., 2024). The core difference between NGHGIs and bookkeeping models in land-use change carbon flux estimation lies in the carbon accounting boundary, especially regarding the attribution of indirect fluxes on managed land (Gidden et al., 2023; He et al., 2024). NGHGIs tend to consider all carbon fluxes on managed land (including both direct fluxes and indirect fluxes triggered by environmental changes) as anthropogenic contributions. In contrast, bookkeeping models primarily account for direct fluxes generated by direct human activities but exclude indirect fluxes, which are considered natural ecosystem responses, from anthropogenic inventories of land-use change. The fact that national reports specifically account for afforestation and ecological restoration projects with high carbon removal potential might also influence the results. The most direct example is the similarity between our estimated carbon emissions (1900–1980) and the results of Yu et al. (2022) (Table 3) because of the lack of significant or widespread land management or engineering projects in China during this period. However, the estimates for 1980–2019 differed greatly because land management practices during this period had a substantial impact. As revealed by Yue et al. (2024), land management has played a crucial role in China's land-carbon balance since 1980."

We are very grateful for your numerous valuable and constructive suggestions. In accordance with your comments, we have diligently revised the manuscript. We remain open to any new questions you may have in the subsequent round of review and are committed to further improving the paper. Thank you for your consideration.