Tsinghua University

April 25, 2023

Dear editor and the anonymous reviewers,

Thanks a lot for your work and time on our manuscript.

The paper entitled ***“Emission trends of air pollutants and CO_2 in China from 2005 to 2021”*** (**Manuscript ID: essd-2022-464**) by Shengyue Li, et al., has been revised carefully according to the correction requests and review reports.

The authors have addressed all the reviews’ comments point-by-point as below. All the corrections and responses have been incorporated into the new revised manuscript and supplement (marked with **BLUE COLORED FONTS**).

If further responses and corrections should be made, please don’t hesitate to let me know.

Yours Sincerely
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Point-by-point detailed responses for the reviewers' comments are listed as follows:

ESSD MS: **essd-2022-464**

Manuscript title: **Emission trends of air pollutants and CO_2 in China from 2005 to 2021**

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Reviewer 1:

Comment 1:

I think China's emission inventory of air pollutants and CO_2 during 2005–2021 (ABaCAS-EI v2.0 dataset) is very meaningful, what are the innovations in this study compared with similar studies? In other words, the authors should point out the novelty of this study by comparing it with related references.

Response 1:

Thank you for the valuable suggestions. First, this study developed a coupled emissions inventory of air pollutants and CO_2 during 2005–2021 (ABaCAS-EI v2.0 dataset) based on a unified emission framework by considering the influences of activity level, technology evolution, and emission control policies. The characteristics of air pollutants and CO_2 emissions were comprehensively analyzed from multiple dimensions such as time, space, sector, and synergies between air pollutants and CO_2 emissions. Compared to previous studies (**Table R1**), this study provides a more comprehensive understanding of the historical co-control process and highlights the future synergistic reduction priorities of air pollutants and CO_2.

To clarify the novelty and contribution of this study, we have adopted the following text in the ABSTRACT of the revised manuscript as follows: "China is facing the challenge of synergistic reduction of air pollutants and CO_2 emissions. However, the studies on its historical progress and future priorities are insufficient. This study compiled China's emission inventory of air pollutants and CO_2 from 2005 to 2021 (ABaCAS-EI v2.0 dataset) based on a unified emission-source framework by considering the influences of activity level, technology evolution, and emission control policies. The characteristics of air pollutants and CO_2 emissions were comprehensively analyzed from multiple dimensions such as time, space, sector, and synergies between air pollutants and CO_2 emissions."

Table R1: Comparison of research contents among similar studies

Elements		This study	Zheng et al. (2018)	Gao et al. (2022)	Zhang et al. (2022)
Dataset		ABaCAS-EI	MEIC	CHRED 3.0A	China Environment Yearbook, CHRED
Time		2005-2021	2010-2017	2018	2012-2018
Spatial scale		province city	nation	city grid (10km)	city
Sector		15 subsectors	5 sectors	21 subsectors	NA
Historical trend	reduction measures	structure adjustment energy & material saving end-of-pipe control	end-of-pipe control	NA	energy use technological progress end-of-pipe control
	co-control achievement	sector province/city	NA	NA	city
Future priority	potential synergistic reduction	sector province/city measure	NA	grid	measure

NA: not analyzed

Comment 2:

In section 2.2, the author needs to explain the significance of the application ratio for CO_2 is set to zero of the CCUS (Carbon Capture, Utilization, and Storage) technologies in this study. In addition, the author needs to elucidate the quality control of different data.

Response 2:

(1) Thanks a lot for your comments. For the question of application ratio of CCUS technologies: Current CCUS technologies in China are still in the stage of scientific research or demonstration with small scale. According to the 'China Carbon Dioxide Capture Utilization and Storage (CCUS) Annual Report (2021) — China CCUS Pathway Study' issued by Chinese Academy of Environmental Planning and other two departments (Cai et al., 2021), there are about 40 CCUS demonstration projects in operation or under construction in China till 2021, with a capture capacity of 3 million tons CO_2 per year, only 0.02% of actual emissions (12.9 billion tons in 2021 based on ABaCAS-EI 2.0). We have included CCUS in the revised database as you suggested. Specifically,

we have calculated the annual CO_2 removal by CCUS technology based on the commissioning time and carbon removal capacity of each demonstration project.

In Section 2.2, **lines 115-118** of the revised manuscript, we have added related explanations of CCUS: "Regarding CO_2 removal, current Carbon Capture, Utilization, and Storage (CCUS) technologies are still in the scientific research or demonstration stage, and the annual carbon capture capacity (3 Mt per year) is only 0.02 % of the actual emissions in 2021 (Cai et al., 2021). Annual CO_2 removal of each province or point source was calculated based on the commissioning time and carbon removal capacity of each demonstration project."

(2) Thank you for the suggestion on data quality control. We paid much attention on the quality of data. According to Eq. (1), there are four types of basic data to calculate emissions: 1) activity data, such as fuel consumption, products, and material consumption; 2) unabated emission factors; 3) measure-specific pollution or carbon removal efficiency; 4) measure-specific application ratios.

Activity data are mostly collected from official sources with good data quality assurance, such as national or regional statistical yearbooks, Industrial census datasets, and related associations. After collection, historical trend analysis will be carried out for each data to avoid abnormal value in a specific year. The detailed data sources for each sector are listed in Table S2. For unabated emission factor data and measure-specific pollution removal efficiency data, some are obtained from localized experiments of our team, and some are collected or integrated from related literature. Measure-specific application ratios are collected from official reports, national environmental statistics, and industrial investigations. All these three types of data have been published or applied in our previous studies and have been rigorously peer-reviewed. Detailed data sources or organizational processes can be found in the published papers (Table S3).

In Section 2.2, **lines 107-115** of the revised manuscript, we have added the description of data quality: "The activity data were mostly collected from official sources with quality assurance. Details of each emission source are presented comprehensively in Table S2. The emission factors of air pollutants were obtained from localized experiments or integrated from related literature, and those of CO_2 were obtained by referring to the guidelines for the emission inventory of greenhouse gases in China (NDRC, 2011) and the guidelines issued by the Intergovernmental Panel on Climate Change (IPCC) (Eggleston et al., 2006; Goodwin et al., 2019). The measure-specific removal efficiencies and their application ratios for air pollutants are collected from official reports, national environmental statistics, industrial investigations, and previous studies (Liu et al., 2018; Liu et al., 2019; Wang et al., 2019; Zheng et al., 2019; Liu et al., 2021; Zheng et al., 2021a). Data on emission factor, measure removal efficiency, and application ratio has been introduced in detail in our previous peer-reviewed research (Table S3)."

Comment 3:

In section 3.1, how to define the growth rate of CO_2 emissions has significantly decreased and has decoupled with GDP?

Response 3:

Thanks for your comment. Organization for Economic Co-operation and Development (OECD, 2002) defines "decoupling" as "decoupling occurs when the growth rate of the environmentally relevant variable is less than that of its economic driving force (e.g. GDP) over a given period." There are generally two degrees of decoupling if GDP displays positive growth: 1) absolute decoupling, which occurs when the growth rate of the environmentally relevant variable is zero or negative; 2) relative decoupling, which occur when the growth rate of the environmentally relevant variable is positive but less than the growth rate of GDP.

As shown in Fig.1, from 2005 to 2011, CO_2 emissions had increased by 68%, which is roughly comparable to the growth rate of GDP (87%). During 2011-2021, the growth of CO_2 emissions decreased to 20% while the GDP growth was up to 91%. According to the definition of OECD, we can conclude that CO_2 emissions have relatively decoupled with GDP in China after 2011.

In Section 3.1, **lines 140-145** of the revised manuscript, we have reorganized our description as follows: "Figure 1 shows the trends in air pollutants and CO_2 emissions in China from 2005 to 2021. All air pollutant emissions have declined since 2013. The CO_2 emissions showed an increasing trend but at a slower growth rate. During 2005–2011, CO_2 emissions had increased by 68%, which is roughly comparable to the growth rate of GDP (87%). However, from 2011 to 2021, China's CO_2 emissions only increased by 20% when GDP growth was up to 91%. It can be concluded that China's CO_2 emissions have relatively decoupled with GDP after 2011 as defined by Organization for Economic Co-operation and Development (OECD, 2002)."

Comment 4:

The authors need to add relevant references to explain energy mix transformation and energy efficiency improvement measures have offset half of the CO_2 emission increase due to the growth of electricity generation in line 185.

Response 4:

Thank you very much for the suggestion. The factors influencing CO_2 emissions from power plants include electricity generation, energy mix, and energy efficiency. During 2005-2021, power generation had a 2.4-fold increase in China. If the energy structure and efficiency were kept at the levels in the year 2005, the CO_2 emissions from power plants would increase by a factor of 2.4. The actual CO_2 emissions from power plants only increased by one-fold, by inference, the energy mix transformation and energy efficiency improvement offset half of the CO_2 emission increase. We have added explanations and references in the revised manuscript.

In **lines 192-199** of the revised manuscript, we have reorganized our descriptions and added relevant references: "Notably, if the energy structure and efficiency were kept at the levels in the year 2005, the CO_2 emissions from power plants would increase by a factor of 2.4, the same increase fold as in total power generation (including fossil fuel and non-fossil energy generation) from 2005 to 2021. However, the actual sectoral CO_2 emissions showed only a 1.0-fold increase. By inference, the energy mix transformation and energy efficiency improvement offset half of the CO_2 emission increase. In terms of the energy structure, the proportion from non-fossil fuel generation increased by 16 % during 2005–2021 (NBS, 2021), especially after 2013 (a 10 % increase from 2013 to 2021). In terms of energy efficiency, the energy consumption rate for electricity supply declined from 370 gce kWh^{-1} (grams of coal equivalent per kWh) in 2005 to 303 gce kWh^{-1} in 2021 (EBCEPY, 2021)."

Comment 5:

In section 3.2.2, the authors discussed the trend of the ratio of all air pollutants to CO_2 for all sectors in China from 2013 to 2021. The authors should strengthen the discussion of the results of the analysis.

Response 5:

Thank you for the suggestion. Our original manuscript did focus more on data analysis and less on the reasons and policy implications behind the figures. In the revised manuscript, we have strengthened the discussion to address the latter. This part aims to clear the potential changes for sectoral synergistic emission reductions after historical mitigations and to identify priority sectors for future synergistic emission reductions.

There are finally four paragraphs in this part in Section 3.2.2 of the revised manuscript. In the first paragraph, we clarified the research purpose as mentioned above. In the second paragraph, we quantified the decrease in the sectoral ratios of air pollutants to CO_2 emissions during 2013-2021. We then discussed the reasons for this phenomenon, namely that the process of reducing air pollutants was faster than that of CO_2, in line with the results of our analysis in previous sections. This result further suggested that the potential for synergistic emission reductions in all key sectors is decreasing. In the third paragraph, we analyzed in detail the characteristics of each ratio (including SO_2/CO_2, NOx/CO_2, $VOCs/CO_2$, and $PM_{2.5}/CO_2$), including quantifying changes in the sectoral ratios with the largest or relatively large values, analyzing the possible reasons in terms of mitigation measures, and identifying the sectors with the largest or relatively large potential for future synergistic mitigation based on the 2021 ratio. In the fourth paragraph, we discussed the limitations of applying emission ratios to find priority sectors for the synergistic reduction in a practical scenario, where the emission ratio is large, and the synergistic potential is high, but the actual synergistic reduction capacity is not necessarily large. This is further explained with the example of the off-road machine sector and the cement industry sector based on their different air pollutants and carbon emission mechanisms.

The details are as follows in **lines 227-263** of the revised manuscript:

"Several studies have indicated that with the exhaustion of end-of-pipe control reduction effects in the future, more ambitious carbon reduction measures would be needed to collaboratively mitigate air pollutants emissions to achieve the World Health Organization air quality guidelines (Cheng et al., 2021; Xing et al., 2020). In this study, to identify sectors with large air pollutant reduction potential per unit CO_2 emission reduction, ratios of air pollutant emissions to CO_2 emissions were calculated for each sector. The larger the ratio, the greater the potential for the synergistic reduction of air pollutants emissions under the same CO_2 reduction level.

In China during 2013–2021, all ratios of air pollutants to CO_2 for key sectors decreased to varying degrees (Fig. 4). Specifically, sectoral SO_2/CO_2, $PM_{2.5}/CO_2$, NOx/CO_2, and $VOCs/CO_2$ ratios declined 49.9 %–99.6 %, 25.0 %–89.2 %, 17.0 %–74.1 %, and 69.0 %–81.1 %, respectively. This probably resulted from the relatively faster emission reduction rates of air pollutants than those of CO_2, thus revealing the faster mitigation progress of air pollutants than that of carbon in China in recent years. The greater the proportion of air pollutants that are reduced, the lesser the air pollutant emissions remain to be synergistically reduced with CO_2 emissions; that is, the synergistic reduction potential of all sectors weakened. Therefore, identifying sectors with greater potential for synergistic emission reductions is even more important to support effective policymaking in the future.

In 2013, the value of SO_2/CO_2 ratio was the highest (6.0) in the industrial boiler sector, followed by the residential fossil fuel combustion sector (4.8). However, in 2021, the highest ratio sector was residential fossil fuel combustion (2.1), with its value being more than four times larger than those of other sectors, indicating the potential priority of this sector to synergistically reduce SO_2 and CO_2 emissions in the future. Energy consumption, particularly from coal combustion, is a major source of SO_2 and CO_2 emissions. As an energy consumption (especially coal) sector with almost no end-of-pipe control, it is reasonable and predictable that the residential sector had the greatest potential for synergistic SO_2 and CO_2 reduction in the future when the reduction potential for end-of-pipe control measures was gradually exhausted. For the NOx/CO_2 and $VOCs/CO_2$ ratios, transport sectors, including on-road vehicles and off-road machines, were primarily focused upon, with more than two times higher values than those of other sectors. Further, although the iron and steel industry sector had the highest $PM_{2.5}/CO_2$ ratio in both 2013 (3.4) and 2021 (1.3), the ratio value gradually decreased. Particularly, the $PM_{2.5}/CO_2$ ratio for the iron and steel industry sector was more than twice that for the other sectors in 2013, while this value reduced to 1.6 in 2021. Other sectors with comparable ratio levels in 2021, such as residential fossil fuel combustion (0.8), off-road machine (0.8), and the cement industry (0.7), are also suggested for consideration in future synergistic reductions of PM and CO_2.

Although the emission ratio results in this study indicated a general direction for synergistic reduction, the ratio only represented the potential of synergistic reduction rather than the real ability, and this gap requires additional attention and further research. This difference may be due to different mechanisms of air pollutants and CO_2 production in different sectors. For example, emissions of both $PM_{2.5}$ and CO_2 from the off-road machine sector were directly related to the oil combustion process, which indicated a high potential and ability of this sector to achieve synergistic emission reduction. In the cement industry, $PM_{2.5}$ emissions mostly originated from material treatment processes (such as cement grinding), and CO_2 emissions mainly resulted from coal combustion and raw material calcination. The independent emission generation processes of $PM_{2.5}$ and CO_2 suggest that although the cement industry sector had a relatively high ratio of $PM_{2.5}/CO_2$, its actual synergistic reduction ability was likely poor. Thus, based on the results of this study and the emission mechanisms, further in-depth analysis, such as that from the perspective of reduction measures, is still needed in the future.”

Comment 6:

In line 252, how to understand the sentence “most provinces only contributed to the air pollutants emission reductions with increased CO_2”

Response 6:

Figure 5 shows that during 2013-2021, the air pollutants emissions of most provinces have decreased but their CO_2 emissions are still increasing. In the revised manuscript **lines 280-281**, we have reorganized this sentence into “most provinces are still experiencing a decline in air pollutant emissions and an increase in CO_2 emissions”.

Comment 7:

In section 3.3.2, the author discussed the city’s performance on the co-control of air pollutants and CO_2 in detail, and also mentioned the comparison between CO_2 and GDP in Section 3.1. whether GDP should be taken into account in the analysis of co-control of air pollutants and CO_2 in cities.

Response 7:

This is really an interesting and valuable suggestion! We have added some discussions about the relationships between the co-control of air pollutants and CO_2 and GRP (gross regional product), based on the analysis of the emission ratio changes with GRP in the revised manuscript; related figures have also been added in Fig. 6 (**Fig. R1**).

The details are as follows in **lines 303-321** of the revised manuscript: “We further explored the relationship between the ratio decline and the city’s Gross Regional Product (GRP). For SO_2/CO_2 and $PM_{2.5}/CO_2$, their decline proportions generally increased as the city GRP increased; in other words, the relatively developed cities, such as Beijing and Shanghai, had the fastest decline in the synergistic reduction potential for SO_2, $PM_{2.5}$, and CO_2 emissions. These cities were mostly located in the key regions of China's air pollution mitigation in the past decade (such as BTHs, YRD, PRD, and Sichuan-Chongqing region), whose reduction intensity (i.e., the application ratio of emission reduction measures) was much greater than that in other cities. At the same time, emission reductions of SO_2 and $PM_{2.5}$ were mainly contributed by end-of-pipe control measures in power plants and industrial sectors (as discussed in Section 3.2.1) that do not have synergistic emission reduction effects. These factors ultimately led to a significant decrease in the potential for synergistic reductions in relatively developed cities. While for NOx/CO_2 and VOCs/CO_2, their decline proportion decreased as the city GRP increased; the more developed cities maintained a higher emission ratio, especially when their GRP was larger than 1000 billion yuan. Unlike SO_2 and $PM_{2.5}$, the decline of synergistic reduction potential in NOx and VOCs with CO_2 is much smaller in more developed cities. Considering the considerable contributions from the transportation sector to NOx and VOCs emissions (Fig. S2), the promotion of new energy vehicles in recent years was probably the main reason, which was recognized as a measure with a high synergistic reduction ability. By the end of 2021, the new energy vehicle population in Shanghai, Beijing, and Shenzhen increased to 635, 507, and 544 thousand, respectively, where the proportions of new energy buses were up to more than 50 %. Although industrial end-of-pipe control measures also contributed to NOx and VOCs emission reductions nationwide, new energy vehicles were more widely promoted in relatively developed cities, which had more vehicles and stronger financial strength than less developed cities. This measure finally avoided a greater decrease in the synergistic reduction potential of NOx and VOCs with CO_2 in more developed cities as in the case of SO_2 and $PM_{2.5}$."

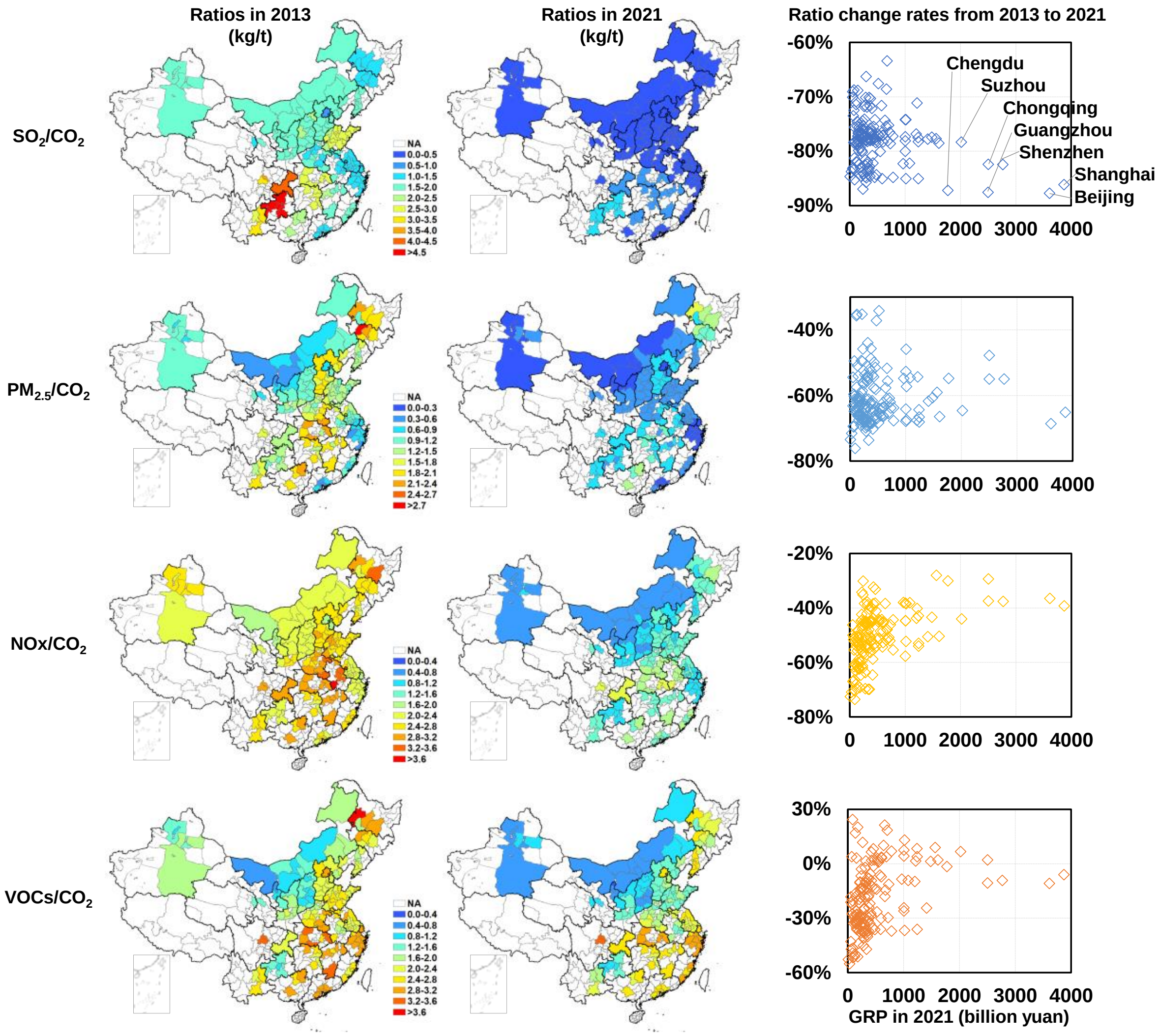

Figure R1 (Figure 6 in the revised manuscript): City's ratios and their change rates of air pollutant emission to CO_2 emission during 2013–2021 in China. (NA: data not analyzed; GRP: Gross Regional Product)

Comment 8:

The authors need to revise the superscript and subscript of words in Figure 9 to make the figure more normalizing.

Response 8:

Thank you for the comments. We have revised the superscript and subscript of words in Figure 9 (**Fig. R2**) in the revised manuscript. The revised figure is as follows:

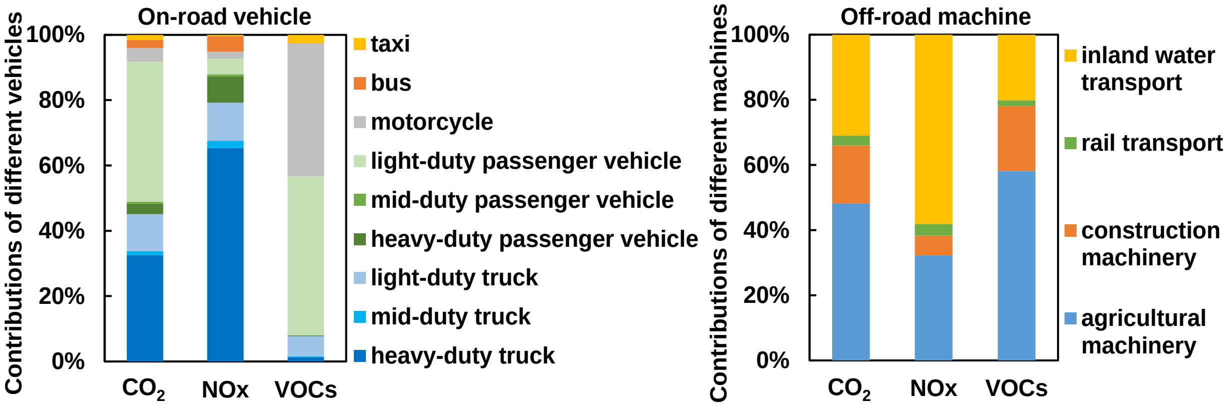

Figure R2 (Figure 9 in the revised manuscript): Emission contributions from different types of transport facilities in 2021 in China.

Comment 9:

Language: there are some of the language errors (tenses, singular/plural) and incomplete sentences in the script. Please check the sentence structure, tenses, and language carefully.

Response 9:

Thank you very much for your suggestions! We have hired a professional team (Elsevier author service for language editing) to polish the language of the original manuscript, focusing on the aspects of tense, grammar, and sentence structure.

Reviewer 2:

Comment 1:

Uncertainties of an emission inventory is major concern for research communities and users. I suggest a separate section on the discussion and description of uncertainties in the dataset from 2005 to 2021 be supplemented.

Response 1:

Thank you for the suggestion. We have added a sperate section "Section 3.5" to discuss the uncertainties of our emission inventory. The added text is as follows in **lines 399-418** of the revised manuscript:

"3.5 Emission uncertainty analysis

Based on the Monte Carlo simulation, the uncertainties in the emission estimation for SO_2, $PM_{2.5}$, NOx, VOCs, NH_3, and CO_2 were within [–30 %, 19 %], [–58 %, 60 %], [–29 %, 32 %], [–54 %, 102 %], [–53 %, 53 %], and [–4 %, 6 %]. Uncertainties in emission inventories were mainly due to a lack of comprehensive or local information on activity data, emission factors, and pollutant removal conditions. The highest uncertainty was observed for VOCs emissions. One important reason for this is that the complexity of VOCs-related emission sources likely introduced great uncertainty in acquiring activity data and testing emission factors. For example, the solvent sector accounts for nearly half of VOCs emissions in China. Although this study has considered nearly 30 types of solvents used in several fields (such as industry, transportation, agriculture, and resident) (Table S1), in real life, each type of solvent includes multiple products with different features (such as solvent-based, water-based, and powder-based) and compositions from various manufacturers. Further, owing to sectoral complexity, there are still no public or official statistics on the consumption of different types of solvents for different applications, and localized testing of emission factors for different types of solvents is also limited. In recent years, several teams have attempted to test solvent-related VOCs emission factors (Sun et al., 2020; Gao et al., 2021). Future studies could combine these works to further reduce emission uncertainties. Additionally, $PM_{2.5}$ emissions also have a relatively high level of uncertainty, which is related to the difficulty in accessing pollutant removal conditions in industrial sectors. In recent years, as emission standards continue to be stringent, end-of-pipe equipment (such as desulphurization, denitrification, and dust removal facilities) has been widely used and rapidly updated in various industrial sectors (Wang et al., 2020; Bo et al., 2021). However, as such data are still subject to a high level of confidentiality and a certain release lag, the emission inventory may not be able to accurately and promptly capture the application and efficiency of the equipment, thus, creating uncertainties in emission estimates. Future inventory updates will require the revision of such data based on new pollution censuses or environmental statistics.”

Comment 2:

The current shortcomings on the current datasets and future further improvements directions and potential should discussed in the final implication section.

Response 2:

Thank you for the suggestion. We have added a paragraph to discuss the current shortcomings and future improvement directions of the dataset in Section 5. The added text is as follows in **lines 451-460** of the revised manuscript:

“However, this emission inventory dataset has certain shortcomings. In terms of species, only conventional pollutants and CO_2 were included in this dataset. However, as research on pollution causes, climate change, and health risks progresses (Cui et al., 2022; Liu et al., 2023; Zheng et al., 2023), the importance and emission estimation needs are gradually increasing for non-conventional pollutants (e.g., semi-volatile and intermediate volatile organic compounds, and heavy metals) and non-CO_2 greenhouse gases (e.g., CH_4 and N_2O). An integrated and coupled dataset containing multiple pollutants and greenhouse gases has yet to be established. In terms of sources, the emission estimation method was relatively simplified and rough for non-industrial sectors such as cooking, livestock farming, and fertilizer application in our dataset. However, the impact of these sectors on air quality and climate change may gradually increase with the standardization and improvement of industrial sector controls (Xu et al., 2022). The methodology for accounting for non-industrial emissions requires further refinement and improvement.”

Reviewer 3:

Comment 1:

Language used is understandable; however, improvement should be done in some phrases e.g "By contracts" may be substituted with "on contrary". Also the use of comma should be revised and used properly

Response 1:

Thank you very much for your suggestions! We have hired a professional team (Elsevier author service for language editing) to polish the language of the original manuscript, focusing on the aspects of phrases, punctuation, grammar, and so on.

Comment 2:

The added value of the paper compared with the up to now literature/publications needs to become more clear

Response2:

Thank you for the valuable suggestions. First, this study developed a coupled emissions inventory of air pollutants and CO_2 during 2005–2021 (ABaCAS-EI v2.0 dataset) based on a unified emission framework by considering the influences of activity level, technology evolution, and emission control policies. The characteristics of air pollutants and CO_2 emissions were comprehensively analyzed from multiple dimensions such as time, space, sector, and synergies between air pollutants and CO_2 emissions. Compared to previous studies (**Table R1**), this study provides a more comprehensive understanding of the historical co-control process and highlights the future synergistic reduction priorities of air pollutants and CO_2.

To clarify the novelty and contribution of this study, we have adopted the following text in the ABSTRACT of the revised manuscript as follows: "China is facing the challenge of synergistic reduction of air pollutants and CO_2 emissions. However, the studies on its historical progress and future priorities are insufficient. This study compiled China's emission inventory of air pollutants and CO_2 from 2005 to 2021 (ABaCAS-EI v2.0 dataset) based on a unified emission-source framework by considering the influences of activity level, technology evolution, and emission control policies. The characteristics of air pollutants and CO_2 emissions were comprehensively analyzed from multiple dimensions such as time, space, sector, and synergies between air pollutants and CO_2 emissions."

Table R1: Comparison of research contents among similar studies

Elements		This study	Zheng et al. (2018)	Gao et al. (2022)	Zhang et al. (2022)
Dataset		ABaCAS-EI	MEIC	CHRED 3.0A	China Environment Yearbook, CHRED
Time		2005-2021	2010-2017	2018	2012-2018
Spatial scale		province city	nation	city grid (10km)	city
Sector		15 subsectors	5 sectors	21 subsectors	NA
Historical trend	reduction measures	structure adjustment energy & material saving end-of-pipe control	end-of-pipe control	NA	energy use technological progress end-of-pipe control
	co-control achievement	sector province/city	NA	NA	city
Future priority	potential synergistic reduction	sector province/city measure	NA	grid	measure

NA: not analyzed

Comment 3:

The preprint presents the estimation of CO_2 and air pollutant emissions in China through the application of ABaCAS-EI v2.0 (Air Benefit and Cost and Attainment Assessment System-Emission Inventory version 2.0) - http://abacas.see.scut.edu.cn/abacas/. However, authors can add some more info on the inventory software especially related to the reduction measures (end-of-pipe) that are included in it.

Response 3:

Thank you for your suggestion, it is really very helpful to improve our website services. We plan to upload some info and data of our inventory to the ABaCAS website after the paper has been received, and the public will probably see the relevant information updated on our website by the end of June. **Table R2** shows the list of information we plan to upload, and **Table R3** shows the content of our data as an example of an end-of-pipe measure application.

Table R2: Information list of ABaCAS-EI v2.0 dataset

NO.	Type	Content
1	Text	Profile of emission inventory and research team
2	Text	Emission source framework
3	Text	Emission inventory methodology
4	Text	Basic data sources
5	Data	Example data of activity level
6	Data	Example data of emission factor
7	Data	Example data of reduction measure application ratio and efficiency
8	Data	Air pollutants and CO_2 emissions during 2005–2021 by species, sector, and province
9	Figure	Example figure of emission trend in China from 2005 to 2021
10	Figure	Example figure of gird emissions in 2021 in China
11	Figure	Example figure of source contributions in 2021 in China

Table R3: Example data of end-of-pipe measures in power plant in China in 2020

Source	Sector	Fuel	Technology	Measure type	Removal species	Measure name [a]	Application ratio	Removal efficiency
Power plant	Coal-fired power	Coal	pulverized coal boiler - sub critical >=300MW	End-of-pipe	SO_2	FGD	100%	96%
					NOx	LNB-SCR	97%	88%
						LNB-SNCR	3%	71%
						LNB	0%	59%
					$PM_{2.5}$	ESP-FF	36.3%	99.8%
						LTESP-WESP	28.6%	98.95%
						FF	5.2%	99%
						LTESP	27.5%	97.26%
						ESP	2.3%	93%

a: FGD, flue gas desulfurization; LNB, low nitrogen combustion technology; SCR, selective catalytic reduction; SNCR, selective non-catalytic reduction; ESP-FF, electrostatic and fabric composite filter; LTESP, low temperature electrostatic precipitator; WESP, wet electrostatic precipitator.

Comment 4:

In the ABaCAS-EI dataset info on end-of-pipe can be provided e.g as a percentage of reduction for each technology used. Some of these reductions are mentioned in the paper. It is very useful to have the information that has been used to estimate the emissions applying the reductions for each air pollutant. or at least to provide reliable sources where to find this info.

Response 4:

Thank you for the comment. Measure-specific removal efficiency and its application ratio for air pollutants can be collected from official reports, national environmental statistics, industrial investigations, and related studies. The data sources have been introduced in our previous studies in detail (same sources as those of emission factors, Table S2). Alternatively, the data we have well organized will be available to the public directly from our ABaCAS website later this year (perhaps June)

In Section 2.2, **lines 111-114** of the revised manuscript, we also added some references to help readers find relevant data more quickly: "The measure-specific removal efficiencies and their application ratios for air pollutants are collected from official reports, national environmental statistics, industrial investigations, and previous studies (Liu et al., 2018; Liu et al., 2019; Wang et al., 2019; Zheng et al., 2019; Liu et al., 2021; Zheng et al., 2021a)."

Comment 5:

Provide more clear indications on the references for the data that are sourced e.g from China Statistical Yearbook, where to find the info on the technologies applied in the China's energy sector (links and table names)

Response 5:

Thank you for the comment. We have added the detailed data source by sector, including links and table names, in Table S2 of the revised supplement (**Table R4**).

Table R4 (Table S2 in the revised supplement): Major data sources of activity data of different emission sources.

Emission sources	Activity data	Major data sources[a]
Power plant	Fuel consumption	China Energy Statistical Yearbook, section 6: Regional Energy Balance Sheets Compendium of statistical data on the electric power industry, Table 2-2: Electricity generation by region

Industrial boiler	Fuel consumption	China Energy Statistical Yearbook, section 6: Regional Energy Balance Sheets China's Environmental Statistics (not publicly released) Industrial investigation (not publicly released)
Residential combustion	Fuel consumption	China Energy Statistical Yearbook, section 6: Regional Energy Balance Sheets China Statistical Yearbook, Table 14-23: Building areas
Transport	Vehicle population	China Statistical Yearbook, Table 16-20: Civil vehicle population China Transportation Statistical Yearbook, Table: Public transport population
	Fuel consumption	China Energy Statistical Yearbook, section 6: Regional Energy Balance Sheets International Energy Agency dataset: https://www.iea.org/ (last access: 25 April 2023)
Open burning	Biomass consumption	China Statistical Yearbook, Table 12-10: Major agricultural products production Satellite observation product of MODIS burned area: MCD64Al, http://modis-fire.umd.edu/ (last access: 25 April 2023)
Industrial process	Industrial product output	China Statistical Yearbook, Table 13-13: Industrial products output by region China Industrial Statistics Yearbook, Table 3-55: Industrial products output by region China Iron and Steel Industry Yearbook, Table 7: Artificial block ore output China Nonferrous Metal Yearbook, Table: Non-ferrous metal output by region China Building Materials Industry Yearbook, Table: Major building materials products output China Chemical Industry Yearbook, Table 8: Major products output China's Environmental Statistics (not publicly released) Industrial investigation (not publicly released)
Solvent	Solvent consumption	China Light Industry Yearbook, Table 2: Major products output China Paint Industry Yearbook, section 3: Architectural coatings market review and development trend outlook China Coating Industry Association dataset: https://www.chinacoatingnet.com/index2.php (last access: 25 April 2023) China adhesives and tape industry association dataset: https://www.catia-china.com/ (last access: 25 April 2023)
Oil storage and transportation	Oil production and sales	China Energy Statistical Yearbook, Table 3-5: Gasoline production by region; Table 3-6: Diesel production by region
Waste treatment	Waste disposal volume	China Environmental Statistical Yearbook, Table 10-6: Municipal wastewater discharge and treatment by region, Table 10-7: Urban appearance and environmental health by region
Agriculture	Livestock stocking	Chinese Animal Husbandry and Veterinary Yearbook, Table: Annual slaughter of major livestock by region, Table: Annual stock of major livestock by region
	Fertilizer application	China Rural Statistical Yearbook, Table 3-6: Chemical fertilizer application amount by region Compendium of cost and income data of national agricultural products, Table: Fertilizer input by crop

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a: All data collected from national yearbooks can be retrieved from the official website of National Bureau of Statistics: https://data.stats.gov.cn/english/, last access: 25 April 2023.

Comment 6:

Section 3.1 line 185 – define to what corresponds the 2.4 fold increase (fossil or coal?)

Response 6:

Thank you for the comment. The manuscript was intended to convey that total electricity generation had increased by a factor of 2.4. Power generation technologies include both fossil and non-fossil energy generation.

In **lines 192-194** of the revised manuscript, we have reorganized this sentence: "Notably, if the energy structure and efficiency were kept at the levels in the year 2005, the CO_2 emissions from power plants would increase by a factor of 2.4, the same increase fold as in total power generation (including fossil fuel and non-fossil energy generation) from 2005 to 2021."

Comment 7:

Figure S1 – EDGAR data stops at 2015. Currently EDGAR CO_2 data are available up to 2021. For air pollutants data are available up to 2018 (EDGAR - The Emissions Database for Global Atmospheric Research (europa.eu))

Response 7:

Thank you very much for the reminding. We have added the newest data of EDGAR into Fig. S1 in the revised supplement (**Fig. R1**).

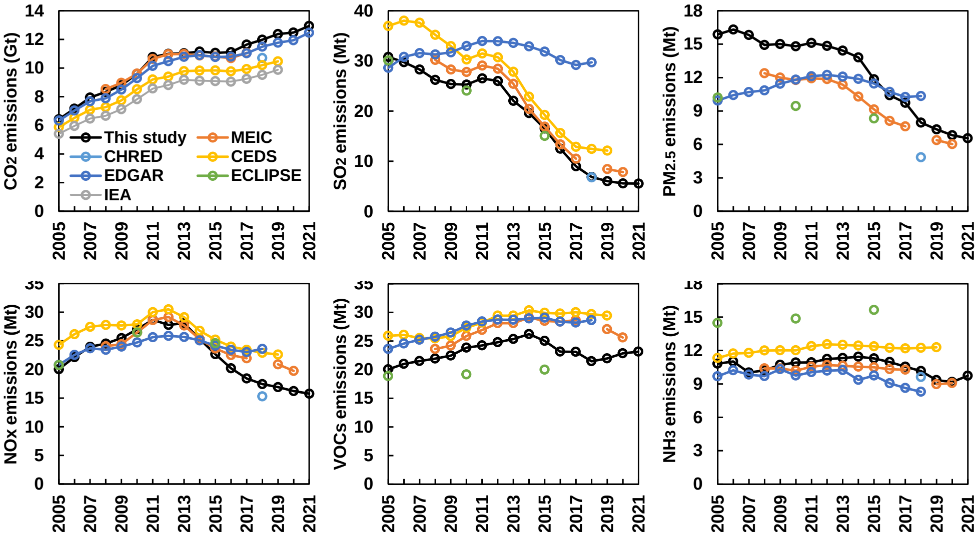

Figure R1 (Figure S1 in the revised supplement): Comparison of China's emission inventories compiled in this study and in other studies.

Comment 8:

The authors should use the footnote or the reference section for the sources that are expressed as links in the text.

Response 8:

Thank you for the suggestion. In the revised manuscript, we have changed the presentation of the relevant sources that were expressed as links in the original manuscript.

Comment 9:

Avoid to insert in the Abstract the reference of the dataset

Response 9:

Thank you very much for the kind reminding. We have rechecked the journal requirement: “At least for the final accepted publication, a functional data set DOI and its in-text citation must be given in the abstract”. Therefore, we consider retaining the DOI and the in-text citation on our dataset in the ABSTRACT.

References:

Gao, Y., Zhang, L., Huang, A., Kou, W., Bo, X., Cai, B., and Qu, J.: Unveiling the spatial and sectoral characteristics of a high-resolution emission inventory of CO_2 and air pollutants in China, Sci. Total Environ., 847, 157623, https://doi.org/10.1016/j.scitotenv.2022.157623, 2022.

Zhang, Q.-Y., Cai, B.-F., Wang, M.-D., Wang, J.-X., Xing, Y.-K., Dong, G.-X., Zhang, Z., and Mao, X.-Q.: City level CO_2 and local air pollutants co-control performance evaluation: A case study of 113 key environmental protection cities in China, Advances in Climate Change Research, 13, 118-130, 10.1016/j.accre.2021.10.002, 2022.

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