Main revisions and response to reviewers' comments

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Title: The effects of energy paths and emission controls and standards on future trends in China's emissions of primary air pollutants

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We thank very much for the valuable comments from the two reviewers, which help us improve the quality of our manuscript. Following is our point-by-point responses to those comments and corresponding revisions.

Reviewer #1

1. The paper predicted annual emissions of SO_2, NO_X, and PM for 2015, 2020, and 2030 based on different scenarios. Is it possible to also include emissions for 2025?

Response and revisions:

We thank the reviewer's comment. Yes, in the revised manuscript, the emissions for 2025 are carefully analyzed with the same methods for 2015, 2020, and 2030. Relevant tables (Tables 2-4) and figures (Figures 2-6) are correspondingly updated as well, integrating the detailed information of the year 2025.

2. Total PM shall be TSP. In addition, the energy related activities also emit VOCs. Is it possible for the authors to give the results of VOCs emissions?

Response and revisions:

We thank the reviewer's comment, and TSP is consistently used in the revised manuscript. We agree with the reviewer that VOC comes partly from energy related

activities. However, high uncertainty might exist under current framework of emission projection in this work, since VOC is less stressed in current emission control polices and standards. It is similar for some other species such as NH_3 and CO. Therefore we have added a paragraph in Section 4.2 in the revised manuscript, with discussion and suggestion for future work for VOC emissions (from line 18, page 24 to line 3, page 25).

3. Page 7923 Line 24-27: although the authors give a reference here, it is better that they give a brief description on how they consider the slower increases in electricity demand and more penetration of renewable power.

Response and revisions:

We thank the reviewer's suggestion. In the revised manuscript, we've added a paragraph explaining the assumptions and the reasons for slower increase in electricity demand and more use of renewable power. It is mainly driven by the decreased electricity consumption per unit production of GDP and the development plan of renewable energy by National Energy Administration of China (lines 2-8, page 8). The most recent report by National Energy Administration is also added as a new reference (Wu, 2013).

Reference:

Wu, J. R.: The perspective for power industry 2012-2050, National Energy Administration, internal report (in Chinese), 2013. Available at: http://www.cpnn.com.cn/

4. MMT used in the manuscript: is it for physical coal amount or coal equivalent? In fig. 1, the MMT is also used for oil consumption, is it MMT oil? Please clarify

Response and revisions:

MMT in the manuscript is used as physical amount unit, both for coal and oil consumption. As required by the reviewer, the units in Figure 1 are clarified in the revised manuscript.

5. Table 1: the authors assume that the recently issued emission standards will be fully implemented under the STD scenario, which means that the emission standards would not be fully implemented under the other two scenarios. At what levels the standards will be implemented under BAS and REF scenarios? What are the rationale of this assumption? This point shall be clarified.

Response and revisions:

We thank the reviewer's crucial comment here. In the BASE, we conservatively assume that emission control levels would be unchanged from those in 2010, and in the REF, new improvements of emission control are taken into account according to the national action plan of air pollution prevention and control (NAPAPPC). Those actual emission levels, however, do not necessarily satisfy the current emission standards, particularly for small and energy-inefficient industrial sources. The reasons include 1) some old and small sources have not been retrofitted with new emission control devices; and 2) the more important, the actual benefits of air pollutant control devices (APCD) are not as sufficient as expected, attributed mainly to relatively poor management and operation of APCDs for cost saving. Such situation still exists across the country according to Ministry of Environmental Protection (MEP) and our field investigation (unpublished yet). In the STD, not only current but also some proposed emission standards with more stringent emission limits are assumed to be fully satisfied, and it is thus an ideal case exploring the potential of those standards on emission abatement. We clarified this at the first paragraph of Section 3 in the revised manuscript (from line 19, page 10 to line 5, page 11).

6. Section 3: There have been quite a few new studies on the emission factors of Chinese sources. This reviewer suggests the authors to include the most recent studies in this paper.

Response and revisions:

We thank the reviewer for pointing this out, and yes, we have checked through the recent studies conducted in China and updated the emission factors, particularly for transportation and residential sectors. We stress this issue in Sections 3.5 (lines 7-8, page 19), 3.6 (lines 22-23, page 19) and 4.5 (lines 5-7, page 29) of the revised manuscript. The relevant papers have been added as new references in the manuscript (Fu et al., 2012; Huo et al., 2012c; Song et al., 2012; H. Zhang et al., 2012; Shen et al., 2013; Wei et al., 2014).

Reference:

Fu, M., Ge, Y., Tan, J., Zeng, T., Liang, B.: Characteristics of typical non-road machinery emissions in China by using portable emission measurement system, Sci Total Environ.,437, 255-261, 2012.

Huo, H., Yao, Z., Zhang, Y., Shen, X., Zhang, Q., He, K.: On-board measurements of emissions from diesel trucks in five cities in China, Atmos. Environ., 54, 159-167, 2012c.

Shen, G., Tao, S., Wei, S., Chen, Y., Zhang, Y., Shen, H., Huang, Y., Zhu, D., Yuan, C., Wang H., Wang, Y., Pei, L., Liao, Y., Duan, Y., Wang, B., Wang, R., Lv, Y., Li, W., Wang, X., Zheng, X.: Field measurement of emission factors of PM, EC, OC, parent, nitro-, and oxy-polycyclic aromatic hydrocarbons for residential briquette, coal cake, and wood in rural Shanxi, China, Environ. Sci. Technol., 47, 2998-3005, 2013.

Song, W. W., He, K. B., Lei, Y.: Black carbon emissions from on-road vehicles in China, 1990-2030, Atmos. Environ., 51, 320-328, 2012.

Wei, S., Shen, G., Zhang, Y., Xue, M., Xie, H., Lin, P., Chen, Y., Wang, X., Tao, S.: Field measurement on the emissions of PM, OC, EC and PAHs from indoor crop straw burning in rural China, Environ. Pollut., 184, 18-24, 2014.

Zhang, H., Wang, S., Hao, J., Wan, L., Jiang, J., Zhang, M., Mestil, H. E. S., Alnes, L. W. H., Aunan, K., Mellouki, A. W.: Chemical and size characterization of particles emitted from the burning of coal and wood in rural households in Guizhou, China, Atmos. Environ., 51, 94-99, 2012.

7. Fig. 2: This figure is hard to read. To make it clearer, I suggest the authors to separate this figure into two. One figure shows the projected trends in penetrations of technologies for typical sources in China from 2010 to 2030. The other one gives the changes of emission factors, which shall be exact values and not the percentage relative to 2010 levels.

Response and revisions:

We thank for the reviewer's comment. In the revised Figure 2, we follow the reviewer's suggestion and indicate the exact values of emission factors in each panel. The detailed penetrations of APCDs are independently provided in Figure S2 and S3 in the supplement, thus we illustrate the penetrations of production technologies and emission factor trends in the same panels for comparisons in Figure 2. The figure captions and the titles of y-axis are improved as required by the reviewer to avoid ambiguity.

8. In current manuscript, only the trends of technologies penetrations and emission factors for NPS are given. I think it is also important to give such information for CPS and 450S.

Response and revisions:

As we mentioned in the manuscript, the penetrations and emission factor trends for CPS and 450S are similar as those for NPS. Given the paper length, we have provided the information for NPS in the main text (Figure 2), and added the information for CPS and 450S in the supplement (Figure S4 and S5, respectively).

9. Fig. 3: results for PM_{10} shall be given.

Response and revisions:

The results for PM_{10} have been illustrated in Figure 3(d) of the revised manuscript, as required by the reviewer.

10. Section 4.2: Except for the emission control levels, the activity levels have significant impacts on future emission trends. The reviewer is wondering whether it is possible to add more discussions on the uncertainties of future energy consumptions used in this study.

Response and revisions:

We thank the reviewer's comment and agree with the reviewer that the projection of energy trends play important roles on future emission estimate. In particular, the energy trends could be significantly influenced by the national/local energy policies that are currently unavailable and thus cannot be combined into the emission inventory framework. We have added a paragraph in Section 4.2 stressing such uncertainties from activity levels, as required by the reviewer (lines 11-18, page 23).

11. Section 4.3: Please include the following study in the comparison: S. X. Wang, B. Zhao, S. Y. Cai, Z. Klimont, C. Nielsen, M. B. McElroy, T. Morikawa, J. H. Woo, Y. Kim, X. Fu, J. Y. Xu, J. M. Hao, and K. B. He. Emission trends and mitigation options for air pollutants in East Asia. ACP, 2014, acp-2013-1012

Response and revisions:

The study has been included in the revised manuscript (lines 20-21, page 4; lines 12 and 20, page 25), and Figure 4 has been revised accordingly, as required by the reviewer.

12. In addition, the reviewer suggests a thorough grammar-checking by a native English speaker before the paper is published by ACP.

Response and revisions:

We thank the reviewer's comment and the language of revised manuscript has been improved by native English speaker.

Reviewer #3

1. *Assumed in the paper removal efficiencies of SO_2 and NO_X measures are lower than for the same type of control installations used in the OECD countries. Reasons for it needs to be better clarified in the paper. In particular, please explain if lower*

efficiencies result from different design and quality of pollution control equipment or is it due to lack of proper operation and maintenance of installed technologies.

Response and revisions:

We thank the reviewer's crucial comment. It is true that the average removal efficiencies of SO_2 and NO_X for emission control devices in China are lower than those in OECD countries. As we mentioned in the paper, the SO_2 removal efficiency was around 70% before 2010 according to national survey of emission sources by Ministry of Environmental Protection of China (MEP). Since then the removal efficiencies have been improved, but they are still lower than expected, as confirmed by MEP and field investigation by the authors (unpublished yet). The main reason is the relatively poor operation and maintenance of installed technologies. In order to save running cost, the air pollutant control devices (APCD) are rarely fully operated, leading to lower emission control benefits, as indicated by MEP. We clarified this issue in Section 3.1 of the revised manuscript (lines 11-14, page 12), and some relevant papers and reports are also added as new references (Xu et al., 2011; Wang, 2013).

Reference:

Wang, F., The control policy for total emission amount of primary pollutants during the 12th Five Year Plan period, presented at the 17th Workshop on SO_2, NO_X, and Hg pollution control technology and $PM_{2.5}$ control and monitoring technology, Hangzhou, China, May 16-17, 2013.

Xu, Y.: Improvements in the operation of SO_2 scrubbers in China's coal power plants, Environ. Sci. Technol., 45, 380-385, 2011.

2. *Page 10: explain why the study assumes that emission standards issued will be implemented only in the STD scenario. This implies non-compliance with standards in the REF scenario. How is it possible? Does it mean that the standards are not part of the NAPAPPC?*

Response and revisions:

We thank the reviewer's comment. NAPAPPC is an action plan of air pollution

control and regulates the various emission control measures by sector including the installation of advanced air pollutant control devices, improving the penetrations of new and energy-efficient manufacturing technologies, using the high-quality fuels, and better distributions of emission sources. However, as a plan issued by the central government, NAPAPPC itself does not specify the emission limits of different types of emission sources, and the actual emission levels do not necessarily satisfy the emission standards, particularly for small and energy-inefficient industrial sources. The benefits of emission control measures may not be as sufficient as expected, attributed mainly to possible poor management and operation of APCDs for cost saving, as we mention in the response to Question 1.

The emission standards made by different industry associations provide detailed information for the emission limits by sector. The STD scenario of this work, therefore, provides an ideal case exploring the potential of those standards on emission abatement. We clarified this at the first paragraph of Section 3 in the revised manuscript (from line 19, page 10 to line 5, page 11).

3. *Page 17, last paragraph: explain how the emission factors were measured: during test cycles or in real-life operating conditions. Current test cycles do not properly reflect the real operating conditions and thus the average emission factors are for some vehicle types and driving modes higher than the values from the test cycles. Vehicle aging is not the only reason for differences.*

Response and revisions:

We thank for the reviewer's comment. All the studies included in the mobile emission factor database conducted on-road measurements, and most of them use the advanced instruments SEMTECH-DS (for gaseous pollutants) and DMM-230 (for particles). Thus the emission factors are obtained in real-life operating conditions. We put the detailed information in our previous work (Zhao et al., Atmos. Chem. Phys., 13, 487-508, 2013) and clarified this in the revised manuscript (lines 4-7, page 19).

We agree that aging is not only reason for differences, the main reasons for vehicle deterioration should be the poor inspection and maintenance, as we have stated in the revised manuscript (lines 9-11, page 19).

4. *Explain why the "best guess" scenario assumes only partial implementation of the NAPAPPC*

Response and revisions:

As we discuss in Section 4.2, not all of NAPAPPC measures can be quantitatively analyzed under current framework of national emission inventory, due to lack of data particularly on individual small emission sources. Besides the national one, moreover, provinces, particularly those with relatively heavy pollution, are making or will make corresponding local action plans for air pollution prevention and control (lines 3-6, page 23). Such kind of information could not be exactly followed currently. Since those limitations have been stressed in the manuscript, the word "partial" is deleted in the revised manuscript to avoid ambiguity (line 12, page 2).

5. *Use TSP (as in the last line of Page 4) or total PM (as on Page 11) consequently in the whole paper.*

Response and revisions:

We thank the reviewer's comment, and TSP is consistently used in the revised manuscript.

6. *Last sentence of abstract and conclusions: what wider range of pollutants do the authors have in mind?*

Response and revisions:

Those pollutants include volatile organic compounds (VOC), NH_3, and CO, which are confirmed to play important roles in atmospheric chemistry and pollution

formation in China. We have stressed this in the abstract (lines 1-2, page 3) and added a discussion paragraph in Section 4.2 of the revised manuscript (from line 18, page 24 to line 3, page 25).

7. *Page 7: MW electric or MW thermal input to the boilers?*

Response and revisions:

It's MW electric (MWe), and we clarified in the revised manuscript (line 12, page 7).

8. *Page 7: Is assumed coal consumption per unit of electricity constant over time? Newer units are likely to have higher efficiency.*

Response and revisions:

We thank the reviewer's comment and agree that newer units have higher efficiency. As we mentioned in the manuscript, the coal consumption of old units is estimated based on the detailed power unit database that is compiled by us and includes the parameter of coal use per unit generation of electricity (expresses as gce/kWh) plant by plant. The difference in energy efficiencies between units can thus be clearly captured. For new ones, since the government requires that all the new-built units should be large units with high energy efficiency, we apply an average ratio of coal use per unit of electricity for China's big power units. We have stressed this point in the revised manuscript (lines 14-16, page 7; line 9, page 8).

9. *Page 7, lines 10 and 11 from the bottom and Table 2: if coal consumption is given in physical tons, provide information on calorific value assumed. If the numbers are in tons of coal equivalent, specify it in the unit.*

Response and revisions:

The coal consumption is given in physical metric tons, and the average heating

value for China's coal is provided in the revised manuscript (lines 22-23, page 7).

10. *Page 14, 1st paragraph: it is unlikely that FGD would be used to reduce emissions from coking. Coke gas desulfurization will be used instead*

Response and revisions:

We thank the reviewer for pointing this out. The words are revised in the manuscript (lines 5-6, page 15).

11. *Page 18, 9th line: explain what the rural vehicles are.*

Response and revisions:

Rural vehicles (RV) are the vehicles used for transportation of goods and passengers in countryside. Tractor is one typical kind of RV. RV can be classified into 3-wheelers (all one cylinder) and 4-wheelers (the number of cylinders is from one through four). RVs are used as trucks but are different from light-duty diesel trucks (LDDTs). Compared to LDDTs, RVs have much smaller engine power, lower designed maximum speed (50-70 km/hr), and lower cost. RVs are forbidden in urban areas and highways because of their low speed and high emission levels. Some of the information has been added into the revised manuscript (lines 15-17, page 9).

12. *Page 18, Section 3.6., 5th line: explain what is assumed. Does the replacement of coal stoves with boilers mean more district heating? Or do you mean replacement of stoves with boilers for single family houses?*

Response and revisions:

We thank the reviewer for pointing this out. It means more district heating and has been stressed in the revised in the manuscript (lines 21-22, page 19).

13. *Page 18, Section 4: Change the title to "Results and discussion"*

Response and revisions:

It has been revised as required (line 1, page 20).

14. *Page 20: do not understand the last sentence of the 1st paragraph. Little (or no) reduction of emissions from Stage III and IV vehicles compared to Stages I and II is due to the fact that the test cycles do not reflect real driving conditions.*

Response and revisions:

We thank the reviewer's comment. As we mentioned in the response to Question 3, the emission levels were measured in real-life condition (i.e., by on-road tests) with advanced instruments (lines 4-7, page 19). Thus we believe the data are reliable.

15. *Page 26, end of Section 4.4: I do not understand the last sentence. Reformulate or delete.*

Response and revisions:

The sentence is deleted in the revised manuscript as required by the reviewer (line 25, page 28).

16. *Conclusions: What does it mean "Compromised operational conditions…e.g., SCR systems"? Does it mean that the efficiency is lower than the design efficiency? Explain.*

Response and revisions:

Yes, it means lower efficiency than expected due mainly to unsatisfied operation and maintenance of APCDs, as we explained in response to Question 1 (lines 11-14, page 12; lines 20-21, page 31).

17. *I could not find the citation of the reference (MIIT, 2010).*

Response and revisions:

We thank the reviewer for pointing this out. The reference is deleted in the revised manuscript.

18. *Figure 4 is difficult to analyze. Suggest replacing with a table.*

Response and revisions:

We thank the reviewer's comment. Since the scenario setting varies significantly between different studies, it is even more difficult to put those data in a table with uniform table header. Thus we put the results from our work in Tables 3 and 4, and compare them with other studies in Figure 4. In the revised manuscript, we tried our best to improve the figure quality, making the symbols bigger and easier to read. The categories of different studies (and thus the series in each panel) are simplified to keep the figure concise.

19. *Figure 5: (a) delete "CPP" from the legend; (b) delete "for CPP+CEM+ISP". Description of the sectors covered in (a) and (b) is in the figure caption. Rename the 2nd axis to % of national total.*

Response and revisions:

Figure 5 has been revised as required by the reviewer.

20. *Table S2: say that values are in percent.*

Response and revisions:

We thank the reviewer for pointing this out, and the caption of Table S2 in the supplement is revised accordingly.

21. *Citations of the references in the supplement are missing. Technical corrections.*

Response and revisions:

We have checked the references and citations to ensure they match in the revised supplement.

22. *Below I suggested couple of changes in the wording for consideration by the Authors. […] means text as it is.*

Page 2, line 8: unit should be teragrams.

Page 6, Section 2.2., 6th line: instead “in details” say “in detail”.

Page 14, last paragraph; replace with: For blast-furnace iron production, a national survey (MEP, 2010) determined current average emission factors for SO2 and NOx at 0.15 and 0.2 kg/t iron. These factors were applied in previous work (Zhao et al., 2013a) and used in BAS and REF cases of this study. Regarding STD…. technologies were investigated (SSC, 2007). The report determined the emission factors at … and PM. These values were used as emission standards…

Page 15, 3rd and 4th lines from the bottom: Better… (Zhao et al., 2013). In REF, more application… than cyclones is assumed, resulting in a considerable reduction…

Page 18, 3rd sentence, reformulate to: This is of course an ideal case providing minimum emission levels for a given vehicle population…

Page 18, Section 3.6: 2nd line: say…implemented in the near future.

Page 19, 5th line: … they may decrease (not it); 6th line: growth of SO_2 emissions is expected (not are)

Page 20, 2nd line: better: … (for 450S) and to 3079 Gg …

Page 21, 8th line from bottom: say … expert judgment had to be applied… (not have)

Page 21, 3rd line from bottom: change to: … uniform emission standards have been set…

Page 22, 7th line from bottom and Page 23, 6th line from bottom: use “differences” (not discrepancies)

Page 25, 2nd paragraph: Change to: Figure 5 shows the … (Figure 5(b) as well as their shares in total national emissions. It is…

Page 25, 7th line from bottom: change to: …the contributions of those sectors to national emissions are estimated to rise again after 2015. The only exception are the emissions of PM10…

Page 26, line 11 from bottom: change to: Implementation of energy saving and emission control measures in those sectors will be challenging because of the geographic dispersion of sources and much greater…

Page 27, 8th line form bottom: change to: …For comparison, the analogous data on PM10 and SO2 emissions for the US (USEPA, 2011) and for the European Union (CEIP, 2011) for the period 1990 to 2010 are shown. In contrast… faster decrease of PM (and thus also Ca) emissions …

Page 28, 1st line: delete "within in".

Page 28, 2nd line: Change to … improvement, further abatement of …acid deposition, if further reduction of SO2 reduction is constrained.

Page 28, 13th line from bottom: change to: … estimate. Figure 7 shows the effects of changes in Chinese emissions between 2005 and 2030 on radiative forcing for five scenarios. Three of them: best guess (NPS-REF), CPS-REF, and 450-REF evaluate the effects of energy paths. The other two: NPS-BAS and NPS-STD demonstrate the effects of control strategies. Global emissions… (in preparation). The latter applies …

Page 28, 5th line from the bottom: play, not played.

Page 29: 1st line: delete “effects”.

Page 29: 5th line. Modify the last sentence of Section 4 as follows: Efforts to reduce emissions from the dispersed (residential) sources…

Page 29, Section 5, 2nd line: replace “measures in energy conservation” with “measures aimed at energy conservation”.

Page 29, last line: replace “at” with “for”.

Page 30, 12th line from the bottom”: replace “discrepancies” with “differences”.

Page 30, 9th line from bottom: say “and their spatial distributions”…

Figure and table captions: skip “The” at the beginning of the captions.

Caption of Figure 2 contains a long explanation. Shorten the caption to the first two sentences and move the rest to the text of the paper. Second sentence, change to: All panels are for the NPS activity scenario.

Caption of Figure 3: Change 2nd sentence to: Values are for the NPS activity scenario and three emission control levels: BAS, REF, and STD.

Caption of Figure 7: Change to: Effects of changes in China’s emissions of air pollutants from 2005 (or 2010 as in the text??) on radiative forcing for selected scenarios analyzed in this work.

Response and revisions:

We thank the reviewer’s very careful comments on language. We’ve taken all of the reviewer’s suggestion and improved the language accordingly in the revised manuscript.