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Atmospheric Chemistry and Physics Discussions

Interactive comment on "CO_2 emissions inventory of Chinese cities" *by* Yuli Shan et al.

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We thank the reviewer's valuable comments and suggestions. We have revised our manuscript according to reviewer's comments. Please download PDF document with format in supplement.

In this manuscript, the authors tried to develop "consistent" methods to estimate the CO2 emission in 20 Chinese cities. Different methods are used to compile the CO2 emission inventory based on the availability of energy consumption and production data. Although I can see the efforts they made to improve the estimation of CO2 emission at the city level, I don't see the scientific significance of this manuscript. Here are my general comments regarding the quality of the manuscript:

1. Overall, the manuscript is not well structured. For example, section "4.1 City choice"

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Discussion paper

can be introduced earlier in the methodology section. The Introduction and Literature Review sections are connected to each other, and it is more appropriate to combine them into one. The Discussion section is totally missing from the manuscript. The tables/figures are not well ordered (e.g., the table S5 is mentioned before table S2, S3, S4).

RE: Thank you very much for the valuable comment. We adjusted the structure of the manuscript as follows:

Firstly, in section "3. Methodology", we discussed the general CO2 emission construction method and data collection methods for Chinese cities with different data availabilities. The set of methods could be applied to most of the Chinese cities, not only the cities chosen in this study. Section 4 is an application of selected cities. So we discussed the city choice in the first paragraph section 4 "Inventory construction and uncertainty of 24 city cases" (We added another 4 case cities in this study. The 24 case cities could make the research more substantial).

Secondly, we moved the challenges for greenhouse gas inventory compilation to the introduction section. Now, the introduction section includes the research background, meaning and challenges. The second part is review of selective literatures on city emission inventory construction, which exposes the current research status and gap of this field.

Thirdly, we add the discussion section as part 5, in which we discussed the emission-socioeconomic characteristics of the case cities and policy recommendation for emission reduction.

Last, we add the validation and uncertainty analysis in section 3.3 and 4.2, and re-ordered the tables/figures.

2. The originality/novelty of the manuscript is not clear based on the Introduction and Literature Review sections. As displayed in the literature review, the city-level CO2

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emissions are already studied in some previous research. The authors suggested that, in the past research, “Above all, there is no unified and consistent compilation method to for Chinese cities’ CO2 emission inventory,”. However, I don’t see the consistency of the methods used in this research either. Different methods are used to estimate the CO2 emission in different cases, and there is no calibration to verify the consistency of the results based on these different methods. The authors need to clarify what is the originality of their research compared to the past studies.

RE: Thank you very much for the valuable comment. We addressed the originality/novelty of the study in the revised manuscript. The emission inventory construction method developed in this study is calculated based on energy balance table, which is consistent and comparable with the national/provincial emission inventory. What’s more, the emission inventories of different cities are constructed in the same method with a consistent structure of provincial and national emission accounts. We believe that our results are consistent among different cities.

“In this study, we develop a feasible methodology for constructing CO2 emissions inventories for Chinese cities for fossil energy combustion and industrial processes, which is consistent with national and provincial emission accounts developed by our previous research and others [1-4]. We collect and compile energy and emission balance tables at city administration boundary level, aiming at providing unified and comparable energy and emission statistics for generic Chinese cities. We verify the method by comparing our results with previous research. We identify the main contributors to CO2 emissions in a selection of 24 Chinese cities, as well as calculating the uncertainties of the estimates.”

“Above all, the current emission inventories of Chinese cities are compiled by sectors, which are not consistent with each other, as well as the national / provincial inventories. The national / provincial inventories are usually compiled according to energy balance tables in China. What’s more, most existing research has focused on a few specific megacities, such as four municipality cities (Beijing, Tianjin, Shanghai and Chongqing)

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and few provincial capital cities, which have consistent and systematic energy statistics."

3. The whole discussion section is missing in the manuscript. The authors simply listed the results in the manuscript, with little interpretation. What do you find from these results, and how do you explain these findings?

RE: Thank you very much for the valuable comment. We add the discussion section as part 5, in which we discussed the emission-socioeconomic characteristics of the case cities and policy recommendation for emission reduction.

4. In the conclusion section, the authors reached two major conclusions: 1) "The first path is reducing the coal share in the energy mix and replacing by low-emission energy types, such as nature gas." 2) "The other way to control CO2 emissions in Chinese cities is reforming the industrial structure with less heavy emission intensity manufacturing industries and more service sectors." These conclusions are universally true for the whole world. Do you really need the city-specific research to get these two general and well-known conclusions? The difficulty is how to replace coal with natural gas, and how to reform the sectors? The authors should make more specific conclusions that are related to their research and based on the interpretation of the result.

RE: Thank you very much for the valuable comment. As we discussed above, cities are the main consumers of energy and emitters of CO2 throughout the world. All the climate change adaption and CO2 emission mitigation policies will be implemented at the city level. Our primary construction of this study is providing a feasible and consistent methodology for constructing CO2 emissions inventories for Chinese cities. We collect and compile energy and emission balance tables at city administration boundary level, aiming at providing unified and comparable energy and emission statistics for generic Chinese cities. Following our method and estimation results, future researches/policy makers could discuss climate mitigation policy. However, we detailed the possible pol-

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icy recommendation in discussion section as well.

“As discussed above, coal and heavy emission intensity manufacturing industries are the primary emission sources within one city. Therefore, in order to reduce the CO2 emissions in Chinese cities, we could take policy from two aspects. The first path is reducing the coal share in the energy mix and develop clean coal utilization strategy. The second one is reforming the industrial structure.

Coal combustion emits more CO2 to produce the same unit of heat compared with other energy types. Replacing coal by clearer energy types, such as nature gas, will help emission control in both Chinese cities and the whole world. In the 12th five-year plan (2011-2015) on energy, the central government proposed to control the total energy consumption and reduce coal share for the first time [5]. Efforts has been taken according to the government document these years and achieved initial success. The coal share in the energy mix decreased from 72.40% to 64.04% in the recent 10 years from 2005 to 2014, while the natural gas share doubled from 2.40% to 5.63%. According to the most up to data research at COP 21, the global carbon emissions decreased slightly by 2015 due to Chinese coal consumption decreasing, and renewable energy increasing globally [6]. Efforts should be planned and undertaken at the city level in the future. For example, we should replace coal gas with natural gas for residential use; cities with geography advantages should develop the renewable energy types, such as wind power, hydroelectricity and nuclear power. Beijing, as the capital city, has a more balanced energy mix compared with other cities. The coal and natural gas share in the energy mix is 20.41% and 21.13%, respectively, in 2014. Therefore, Beijing’s CO2 emissions has remained stable since 2007 and has seen a slight decrease in recent years [7, 8].

The other way to control CO2 emissions in Chinese cities is reforming the industrial structure. Firstly, we should close all the non-permission coal mining and consuming enterprises, in which the kilns are usually backward and produced a lot of CO2 emissions with low economic outputs. All the private and unregulated energy enterprises

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should be integrated into the corporations with the most developed and clean energy technologies. secondly, the city government should also replace heavy emission intensity manufacturing industries with services sectors. Reviewing the emission intensity of the 24 case cities, we could find that cities with more heavy manufacturing industries usually have a higher emission intensity, such as Jixi, Huangshi, Hohhot, Zunyi and Tangshan. On the contrary, cities with more service sector activities have a smaller emission intensity, such as Shenzhen, Chengdu, Xiamen and Guangzhou. Through reforming the industrial structure, Chinese cities may not reduce CO2 emissions at the expense of economic development, and achieve both environmental and social objectives."

Here is a list of specific comments that may help the authors to improve the quality of the manuscript:

1. L28: It is too arbitrary to say this. Some climate policy/goals may not rely on the emission sources, for example, urban planning and land uses.

RE: Thank you for your valuable comment, we have changed to "Understanding the emissions sources in Chinese cities using a feasible and consistent methodology is the basis for many climate policy and goal research in the future."

2. L34: These numbers are questionable. The world's total population is only 220 million / 0.13 = 1.7 Billion in 1990? This is too small.

RE: Thank you for your comment, the year should be 1900. We have corrected the mistake.

3. L52: "table" should be "tables"

RE: Thank you for your comment, we have corrected the mistake.

4. L66-84: The tense is not consistent in the review of past research. The present tense and past tense are messed up.

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RE: Thank you for your comment, we have changed all the tense into past tense.

5. L67: "sectors set" should be "sector sets"?

RE: Thank you for your comment, we have corrected the mistake.

6. L70-72: Is it for one city, or multiple cities, or for the whole world?

RE: Thank you for your comment, the paper is for 12 Chinese provincial cities. “Wang et al. [9] calculated carbon emissions of 12 Chinese provincial capital cities by 6 sectors, including industrial energy consumption, transportation, household energy consumption, commercial energy consumption, industrial processes and waste.”

7. L72-75: This sentence is confusing. It seems "their" sometimes refers to the "researchers", and sometimes refers to the "factors". Also, the subject is missing in the second part of the sentence. "Who" analyse their influence?

RE: Thank you for your comment, we have rewritten this part. “Differently, Kennedy et al. [10] and their subsequent research [11] compiled carbon emissions inventories that cover electricity, heating and industrial fuels, ground transportation fuels, aviation and marine transportation, industrial processes and product use, and waste for 10 global megacities. In accordance with this method, Kennedy et al. [12] complied the greenhouse gas inventories of 22 global cities, including 3 Chinese cities: Beijing, Tianjin, and Shanghai. Furthermore, Kennedy et al. [13] quantified the energy and material flows through the world’s 27 megacities, including four Chinese cities: Beijing, Shanghai, Guangzhou, and Shenzhen.”

8. L88: What is scope 1 and 2? Please explain.

RE: Thank you for your comment, we add the explanation of scope 1 and 2 in the paper. “Scope 1 emissions include CO2 induced from direct use of primary energy and industrial activity within territorial boundary. Scope 2 emissions refer to the out boundary purchased electricity related CO2 emissions”

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9. L93: "to" seems redundant here.

RE: Thank you for your comment, we have corrected the mistake.

10. L93: it is not clear how the authors concluded "there is no unified and consistent compilation method....." based on the above paragraph that discusses the CO2 emission inventories in China. The compilation methods are not discussed clearly. Are they inconsistent within each individual study or between studies?

RE: Thank you for your comment. The previous studies on city's emission inventory are inconsistent between studies, and they are also inconsistent with the national/provincial emission accounting.

"The current emission inventories of Chinese cities are compiled by sectors, which are not consistent with each other, as well as the national / provincial inventories. The national / provincial inventories are usually compiled according to energy balance tables in China. What's more, most existing research has focused on a few specific megacities, such as four municipality cities (Beijing, Tianjin, Shanghai and Chongqing) and few provincial capital cities, which have consistent and systematic energy statistics."

11. L103: You already mention "it is difficult to define a city's boundary ..... because....." in line 99. It is redundant to mention "This leads to a great challenge in defining a city's boundary ....." again.

RE: Thank you for your comment, we have moved this part to section 1 and rewritten it. "First, it is difficult to define a city's boundary for greenhouse gas emissions accounting because energy and material flows among cities may bring a large quantity of cross-boundary greenhouse gas emissions [14, 15]. Commercial activities are much more frequent among cities, compared with inter-provinces / nations, which leads to a great challenge."

12. L103-105: These two sentences express kind of the same meanings.

RE: Thank you for your comment, we have moved this part to section 1 and rewritten

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it. “Second, data for energy consumption and industry products are incomparable and very limited for most cities in China [3]. Data used in previous studies are from various sources, including city statistical documents, remote sensing images, direct interviews with local governmental officials, and published reports and literature [16]. Those data require systematic reviews for consistency and accuracy.”

13. L106: You can just list the sources here. No need to repeat "data from" again and again. For example, data from city statistical documents, remote sensing images, governmental officials, and reports and literature.

RE: Thank you for your comment, we have moved this part to section 1 and rewritten it. “Second, data for energy consumption and industry products are incomparable and very limited for most cities in China [3]. Data used in previous studies are from various sources, including city statistical documents, remote sensing images, direct interviews with local governmental officials, and published reports and literature [16]. Those data require systematic reviews for consistency and accuracy.”

14. L110: It is not necessary to list this sentence as a single paragraph here. You can refer to it where you mention it the first time.

RE: Thank you for your comment, we have removed this sentence.

15. L115: "emissions refer" or "emission refers"

RE: Thank you for your comment, it should be “emissions refer to”.

16. L129: Please write out the full words ("SI") the first time you mention it.

RE: Thank you for your comment, we have correct all the relevant mistakes.

17. L130: Why it jumps from Table S1 to Table S5? Table S2, S3, and S4 are not referred to yet. It is best to refer to the tables/figures in sequence.

RE: Thank you for your comment, we have correct all the relevant mistakes.

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18. L133: This corresponds to the exclusion of "electricity". What is the reason to exclude "heat consumption"?

RE: Sorry for the misunderstanding, we have rewritten this part as “Emissions from electricity and heat generated within the city boundary are counted based on the primary energy input usage, such as raw coal [17]. Our administrative territorial emission inventory excludes emissions from imported electricity and heat consumption from outside the city boundary, as well as the inter-city transportation energy consumption. We only focus on fossil fuel consumed within the city boundary.”

19. L143: what does "sj" mean here?

RE: “s” and “j” are the subscripts, s represents items in energy balance table and j represents 20 energy types. We add definitions in the first paragraph of section 3.3 now. “The subscript sâĹĹ[1,31] represents items in energy balance table; iâĹĹ[1,47] represents all the socioeconomic sectors considered in this study for emission inventory construction (including 40 industry sectors iâĹĹ[2,41]); jâĹĹ[1,20] represents 20 energy types; and tâĹĹ[1,9] represents 9 main industrial products.”

20. L145-158: It is not clear what "The table" means in the whole section 3.2.1. It seems sometimes "the table" refers to the EBT in general, but sometimes it refers to a specific table (e.g., table 2). Please clarify this.

RE: Thank you for your comment, we have rewritten this part and clarify this. “The basic EBT is an aggregate summary of energy production, transformation and final consumption in one area [18], which could reveal the energy flow of one region. The sectoral consumption of fossil fuel types from EBT can be used as activity data to calculate the fossil fuel-related CO2 emissions. Detailed illustration of EBT are shown in SI section 2.”

21. L145: What are primary and secondary energy flows? Please explain.

RE: We have rewritten this part. We use energy flow graph of Beijing to explain the

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energy balance table. “The basic EBT is an aggregate summary of energy production, transformation and final consumption in one area [18], which could reveal the energy flow of one region. The sectoral consumption of fossil fuel types from EBT can be used as activity data to calculate the fossil fuel-related CO2 emissions. Detailed illustration of EBT are shown in SI section 2.”

22. L147: You already abbreviated Energy Balance Table as "EBT". It may be better to use it.

RE: Thank you for your comment, we changed all the “energy balance table” to “EBT” for short.

23. L150: Table 2 is confusing. It says Table 2 is constructed in four parts in line 150, but the table lists 31 items. The "four parts" are mixed with all other items?

RE: Thank you for your comment. We have reformed the table and rewritten this part to avoid misunderstanding. The energy balance table and explanation are moved to Support Information as well. “From Figure S1 and Table S5, we can see that EBT includes 28 items which could be summarized to four parts. “Primary energy supply” provides the information of energy supply, such as production and import; “Input and output of transformation” refers to the primary energy input and secondary energy output in energy transformation process; “Loss” covers all the non-combustion energy loss during the transportation, transformation and utilization; “Final consumption” covers all energy supplied to the final consumer for all energy uses. Especially, “Non-energy use” in the final consumption refers to energy consumed without burning, such as used as chemical material.”

24. L150-158: The explanation of the four parts is confusing. The "four parts" should be defined more clearly and consistently. It is not clear why energy burning consumption equals to “Final consumption” + “Transformation - thermal power / heating supply” – “Loss” – “Non-energy use”, what does "Transformation - thermal power / heating supply" represents? Does the "Loss" only represents the "loss during the utilization"?

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RE: Thank you for your comment. We explained energy balance table and energy burning consumption detailed in the revised manuscript (Support Information). “Energy burning consumption in one region are only presents in two parts in EBT: “thermal power / hearting supply” in “transformation” and the whole “final consumption” exclude “non-energy use” and “loss”. The rest part of EBT shows the production and non-combustion transformation of energy types, which don’t emit CO2. Therefore, we calculate the energy burning consumption as “Final consumption” + “Transformation - thermal power / heating supply” – “Loss” – “Non-energy use” in this study. The fossil fuel related CO2 emissions are calculated based on the energy burning consumption.”

25. L153: How about the loss during other process, such as production, transportation, and transformation?

RE: Energy loss during other process are also included in the Loss part. “Loss covers all the non-combustion energy loss during the transportation, transformation and utilization.”

26. L161: what does "s" represent here?

RE: “s” is the subscripts, representing items in energy balance table. We add definitions in the first paragraph of section 3.3 now. “The subscript sâĹĹ[1,31] represents items in energy balance table; iâĹĹ[1,47] represents all the socioeconomic sectors considered in this study for emission inventory construction (including 40 industry sectors iâĹĹ[2,41]); jâĹĹ[1,20] represents 20 energy types; and tâĹĹ[1,9] represents 9 main industrial products.”

27. L168: please explain this formula. What is i, and what are the two numbers here?

RE: “i” is the subscript, representing all the socioeconomic sectors considered in this study for emission inventory construction. We add definitions in the first paragraph of section 3.3 now. “The subscript sâĹĹ[1,31] represents items in energy balance table; iâĹĹ[1,47] represents all the socioeconomic sectors considered in this study for

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emission inventory construction (including 40 industry sectors iâĹĹ[2,41]); jâĹĹ[1,20] represents 20 energy types; and tâĹĹ[1,9] represents 9 main industrial products."

28. L174: What is "AD"?

RE: "AD" refers to activity data, we defined all the abbreviation in the first paragraph of section 3.3 now to avoid confusing. "As shown in Figure 1, we need the basic energy balance table (ãĂŰEBTãĂŮ_sj), industrial sectoral energy consumption (ãĂŰADãĂŮ_ij), and industrial products' production (ãĂŰADãĂŮ_t) to calculate the CO2 emissions from both fossil fuel combustion and industrial process."

29. L176: why it starts from 2?

RE: Sorry for the confusing. The subscript i refers to all the socioeconomic sectors, the first one is "primary industry". From item 2 to item 41 is industry sub-sectors. We add definitions in the first paragraph of section 3.3 now. "The subscript sâĹĹ[1,31] represents items in energy balance table; iâĹĹ[1,47] represents all the socioeconomic sectors considered in this study for emission inventory construction (including 40 industry sectors iâĹĹ[2,41]); jâĹĹ[1,20] represents 20 energy types; and tâĹĹ[1,9] represents 9 main industrial products."

30. L280: the whole section "4.1. City choice" is more appropriate to put in the "Methodology" section.

RE: Thank you for your comment. We have removed this part and reformed the structure, as discussed in the general comments part.

31. L288: Where is the discussion? It seems the whole discussion section is missing in the paper. RE: Thank you for your comment. We have added the discussion section in section 5, in which we discussed the emission-socioeconomic characteristics of the case cities and policy recommendation for emission reduction.

32. L386: What do you mean by "consistent" here? Different methods are used to estimate the CO2 emission in this paper, and I don't see the consistence here.

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RE: Thank you for your comment. We argue that our accounting approach is consistent. Firstly, the emission inventories of different cities are constructed in the same method with the uniform structure. We only use different approach to reduce data (energy balance table). We believe that our results are consistent among different cities. Secondly, our result is consistent with the national/provincial emission inventories. Both of the national/provincial emission inventory and our city emission inventory are calculated based on energy balance table. They are constructed in the same way with the uniform structure, otherwise than the previous city emission research calculated by sectors.

33. L388: understanding

RE: Thank you for your comment, we have corrected the mistake.

34. What do you mean by "most developed"? You need to support your statement when you mention it.

RE: Thank you for your comment. When we say the city is most developed, we actually mean the city is affluent with well-developed tertiary industry sectors. We rewrote the sentence as “Therefore, the CO2 emissions of Shenzhen’s service departments are higher than those of other cities. The well-developed tertiary industry makes Shenzhen more affluent than other cities, the rural population of Shenzhen is 0 and per capita GDP is 106,880 Yuan in 2010, much higher than the national average level of 41,908 Yuan”.

Reference [1] Shan Y, Liu J, Liu Z, Xu X, Shao S, Wang P and Guan D 2016 New provincial CO2 emission inventories in China based on apparent energy consumption data and updated emission factors Applied Energy [2] Liu Z, Guan D, Wei W, Davis S J, Ciais P, Bai J, Peng S, Zhang Q, Hubacek K and Marland G 2015 Reduced carbon emission estimates from fossil fuel combustion and cement production in China Nature 524 335-8 [3] Liu Z, Liang S, Geng Y, Xue B, Xi F M, Pan Y, Zhang T Z and Fujita T 2012 Features, trajectories and driving forces for energy-related GHG emissions from

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Chinese mega cites: The case of Beijing, Tianjin, Shanghai and Chongqing Energy 37 245-54 [4] Liu Z 2016 Carbon Emissions in China: Springer) [5] NDRC 2013 The 12th Five-Year Plan for Energy Development. [6] Le Quéré C, Moriarty R, Andrew R, Canadell J, Sitch S, Korsbakken J, Friedlingstein P, Peters G, Andres R and Boden T 2015 Global Carbon Budget 2015 Earth System Science Data 7 349-96 [7] Shan Y, Liu J, Guan D and Liu Z 2016 New provincial CO2 emission inventories in China, 2000-2012. [8] Guan D, Liu Z, Wei Y, Shan Y and Zhang Q 2016 Performance assessment for China's energy policies in emission controls. [9] Wang H, Zhang R, Liu M and Bi J 2012 The carbon emissions of Chinese cities Atmospheric Chemistry and Physics 12 6197-206 [10] Kennedy C, Steinberger J, Gasson B, Hansen Y, Hillman T, Havránek M, Pataki D, Phdungsilp A, Ramaswami A and Mendez G V 2010 Methodology for inventorying greenhouse gas emissions from global cities Energy Policy 38 4828-37 [11] Kennedy C, Steinberger J, Gasson B, Hansen Y, Hillman T, Havranek M, Pataki D, Phdungsilp A, Ramaswami A and Mendez G V 2009 Greenhouse gas emissions from global cities Environmental science & technology 43 7297-302 [12] Kennedy C, Ibrahim N and Hoornweg D 2014 Low-carbon infrastructure strategies for cities Nature Climate Change 4 343-6 [13] Kennedy C A, Stewart I, Facchini A, Cersosimo I, Mele R, Chen B, Uda M, Kansal A, Chiu A and Kim K-g 2015 Energy and material flows of megacities Proceedings of the National Academy of Sciences 112 5985-90 [14] Liang S and Zhang T 2011 Urban metabolism in China achieving dematerialization and decarbonization in Suzhou Journal of Industrial Ecology 15 420-34 [15] Wolman A 1965 The metabolism of cities Scientific American 213 179-90 [16] Xi F, Geng Y, Chen X, Zhang Y, Wang X, Xue B, Dong H, Liu Z, Ren W, Fujita T and Zhu Q 2011 Contributing to local policy making on GHG emission reduction through inventorying and attribution: A case study of Shenyang, China Energy Policy 39 5999-6010 [17] Peters G, Weber C and Liu J 2006 Construction of Chinese energy and emissions inventory (Trondheim, Norway: Norwegian University of Science and Technology) [18] Qiu D 1995 Energy planning and system analysis [Chinese document] (Beijing, China: Tsinghua University press)

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Please also note the supplement to this comment:
http://www.atmos-chem-phys-discuss.net/acp-2016-176/acp-2016-176-AC2-supplement.pdf

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