

## ***Interactive comment on “CO<sub>2</sub> 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.

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In this study, the authors proposed a method to compile emission inventories for Chinese cities. The authors applied the proposed method to 20 Chinese cities and compiled inventories. I fully agree with the authors that quantifying and understanding emissions from cities will be a key for better greenhouse gas emission management and maybe the inventory compilation method the authors proposed could be a helpful tool for China. However, as a reviewer of ACP, I do not recommend this manuscript for publication because of several reasons:

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1. The relevance to ACP First of all, I do not think this study falls into the scopes of ACP. Emission inventories can be used as an input for atmospheric transport model simulations. In that way, I do think an emission inventory development does fall into the scope of ACP. However, this study only touched the methodological aspect of emission inventory development (which is maybe fine if published as a tech report) and I did not see any direct scientific implications for atmospheric chemistry/physics. I have no doubt that this manuscript would be more appreciated if submitted to more relevant journal that discusses climate change, emission management/mitigation and etc, given the contents of the work (especially the suggested emission mitigation pathways presented in the conclusion). I believe the authors would be able to find much more appropriate arena to discuss this study. I personally highly doubt that this study (given the current form) would meet the interest of the audience of ACP. Ref: [http://www.atmospheric-chemistry-and-physics.net/about/aims\\_and\\_scope.html](http://www.atmospheric-chemistry-and-physics.net/about/aims_and_scope.html)

RE: Thank you very much for your comment. We argue that this paper conforms to the scopes of ACP.

Firstly, this paper is submitted to Special Issue “East Asia emissions assessment (EA2)”. The authors think that this study falls into the scopes of ACP and EA2. First of all, EA2 focuses on different emission estimation approaches in East Asia, including “development of novel emission inventory models”. This study develops a feasible model of CO<sub>2</sub> emission inventory construction for Chinese generic cities. Therefore, this study conforms to the scope of EA2.

“Organized by the Global Emissions Initiative (GEIA) China Working Group, the East Asia Emissions Assessment (EA2) is designed to bridge these gaps through the integration of different approaches. The assessment includes inter-comparison of current bottom-up inventories in East Asia, development of novel emission inventory models, observation-based constraints on emissions, and evaluation and uncertainty analysis of different emission quantification approaches. The outputs from EA2 studies will not only help reduce uncertainties in East Asia inventories, but also provide improved

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emission quantification methodologies that can be applied to other world regions.”

What’s more, ACP has published several articles about emission inventory estimations, such as “NO<sub>x</sub> emission estimates during the 2014 Youth Olympic Games in Nanjing”[1], “High-resolution inventory of ammonia emissions from agricultural fertilizer in China from 1978 to 2008”[2]. Especially, “The carbon emissions of Chinese cities” (doi:10.5194/acp-12-6197-2012)[3] constructed the carbon emission inventory for 12 Chinese cities based on the sectoral bottom-up approach.

Also, we have talked with Dr. Gregory Frost (the special issue editor). He said that “Development of emissions inventories certainly does fall within the scope of ACP. In order for such work to be of interest to the ACP readership, however, the results must go beyond producing the inventory dataset. ACP manuscripts must also present either some impacts of the inventory on atmospheric chemistry and physics, some validation of the derived inventory with atmospheric observations, comparisons of the inventory with alternative bottom-up approaches, or at the very least, a detailed accounting for the uncertainties in the inventory”. Therefore, we compared our inventories with results from bottom-up approach (see section 3.4 Validation), and calculated the uncertainties in our inventories (see section 4.2 Uncertainty Analysis).

2. The conclusions are not yet reached The authors emphasized that the importance of developing consistent and concrete emission inventories for Chinese cities (which I fully agree with). However, the method proposed in the manuscript does not have any consistency that holds scientific significance. I do acknowledge that the authors calculated emissions for cities in a systematic way in the framework the authors proposed. But it does not mean the emission estimates can be fully compatible to emission estimates from other studies for instance. Given the different levels of deductions implemented for different cities (to compensate the lack of data), I highly doubt that emission estimates for different cities can be compatible. It is hard to believe that without examining the method proposed and evaluating the emission estimates calculated. The authors could compare their results to different studies, although the numbers of previous studies are

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not so large. At the section 2.2, the authors defined two challenges in developing Chinese city emission inventories: 1. The definition of cities (difficulty in dealing with lateral inflow/outflow) and 2. Data availability. First, I think these are common issues for any other cities, not just Chinese cities. Second, this study is not addressing those issues at all. The authors did not acknowledge very clearly, but issues of inflow/outflow still remain in this study and cannot be mitigated by just changing the definition. The authors tried to address the data availability issue by deducing some information lacking. But without showing any validity of the method, the authors cannot claim that the issue is addressed. It is hard to believe that emissions are calculated accurately (and consistently) based on information deduced from data with limited availability. Some of the assumptions are really major (e.g. use province as a proxy for cities). The authors just touched on this as a limitation in the conclusion, but the assumptions need to be tested at least if it is valid or not, especially some of the conclusions are drawn using the results (e.g. emission mitigation pathways). The text is well written, but the authors need to support their claims by the results. In addition to the lack of evaluation and validation, I would like to point out the lack of traceability as well. I could not reach to Yearbooks from the citations. I don't think that is just because of the fact that I do not know Chinese language.

RE: Thank you very much for your comment.

Firstly, the authors do agree that there are some uncertainties in our emission estimates, however, this is the most accurate results we can achieve based on the most comprehensive activity data we can ever find now. Research on cities' emission estimation is at the very beginning stage. It's quite necessary to estimate the cities' emission inventories with the currently available data. This can be the basis of any further research. To tackle the uncertainty issue, we add "uncertainty analysis" in section 4.2 in our revised manuscript.

"Analysing uncertainty is an important tool for improving emission inventories that contain uncertainty [4, 5]. Different methods are used to analyse the uncertainty of emis-

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sions, Jonas et al. [6] describe four relevant uncertainty terms and six techniques that can be used to analyse uncertain emission changes. In this study, we employ Monte Carlo simulations to calculate the uncertainties of 20 Chinese cities' CO<sub>2</sub> emissions, which is recommended by IPCC [7] and widely used in previous research [8]. As the CO<sub>2</sub> emission is calculated as product of activity data and emission factors, therefore uncertainty comes from two parts: activity data (fossil fuel consumption) and emission factors. According to Monte Carlo analysis, we should assume individual probability density functions for the two variables firstly, then simulate the CO<sub>2</sub> emissions values with the assumed functions for many times [9]. Industrial processes emit much less CO<sub>2</sub> (9.89% of the total CO<sub>2</sub> emissions) compared with fossil fuel combustion. What's more, emissions from industrial process are generally with less uncertainties [10, 11]. Therefore, we only consider uncertainty from fossil fuel consumption in this study. We calculate the uncertainty of both the overall CO<sub>2</sub> emissions and sub-sectors' emissions of the 24 city cases in this study.

We assume normal distributions for both activity data and emission factors [10, 11]. The coefficients of variation (CV, the standard deviation divided by the mean) of different emission factors and fossil fuel consumptions are chosen from previous literatures, see Table 3. We repeat the simulation procedure for 20,000 times in Monte Carlo analysis. Table 4 shows the total uncertainties of 24 cities' emissions in 2010 with 95% Confidence Interval.

The average uncertainty of total CO<sub>2</sub> emissions of the 24 case cities is from -4.08% to 4.09%, falling in the range of 10% to 20% for non-OECD countries [12, 13]. This illustrates that our estimations are relatively accurate and realizable. Among the 24 cities, CO<sub>2</sub> emissions of Shenzhen have the smallest uncertainty (-1.72%, 1.70%), while emissions of Jixi have the highest uncertainty (-5.84%, 5.79%). As the largest contributor of CO<sub>2</sub> emissions (39.19% of the total emissions averagely of the 24 cities in this study), the emissions from electricity generation sector has the largest uncertain averagely (-5.70%, 5.75%) among different sectors. This is caused by large amount

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of coal combusted in coal-fired power plant, uncertainty of coal's emission factor is the highest among energy types, despite the fossil fuel consumption in electricity generation sector has a low uncertainty. In contrast to power plant, CO<sub>2</sub> emission from service sector (transportation and territorial industries) have the lowest uncertainty averagely (-1.87%, 1.88%). Much oil and gas are used in these sectors compared with power plant, which have lower uncertainties of emission factor. Detailed uncertainties by sectors are shown in SI Table S9.”

Secondly, restrained by the poor data quality of Chinese data, different data for inventory construction are missing for different cities. Based on the assumption that all cities in one province have the same efficiency of energy use, we deduce the lacking city data with province data. 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 (We do analysis the different emission characteristics of different cities in the result section).

The government only provide national and provincial energy inventory in China. Our previous research has been able to construct emission inventory for China and its provinces [10, 14-16]. Now, we are tackling the city level emission inventory which government does not provide at all. City level emission estimation is a more complex and less data available. We develop this method and utilize currently available energy data to construct emission inventory (which will benefit academic users). Itself is a scientific contribution already.

Thirdly, the authors fully agree that the results should be compared to different previous studies. The comparison will help to verify and reduce the uncertainty of the results. However, it's very different to do the comparison. Because there is no previous research focus on the generic Chinese cities. City emission of Chinese cities is the most

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innovative topic, all of the previous researches on this topic focused on a few specific megacities, such as municipality cities (Beijing, Shanghai, Tianjin, and Chongqing) and few provincial capital cities, which have consistent and systematic energy statistics.

We compared the fossil fuel-related CO<sub>2</sub> emissions of 5 cities with results from our research partner (Chinese academy for environmental planning, CAEP). CAEP estimates the emissions based on energy consumption data collected in a bottom-up way based on industrial facility data and other supporting information. The 5 cities contain all the different cases we deduce the city's data. The result shows that the difference of CO<sub>2</sub> emissions between our study and CAEP's research is within 10%. According to previous research, emissions from OECD countries may have an uncertainty of 5% to 10%, while the uncertainty for non-OECD countries may be 10% to 20% [12, 13]. Therefore, we believe our estimations are relatively accurate and our method is effective and reliable.

Fourthly, it's true that the challenges are common for all cities. The production-based emission inventory constructed in this research (adopting the IPCC administrative territorial scope) doesn't involve the inflow/outflow issue among cities. By using our production-based emission inventory and economic models, further research could estimate the consumption-based emission inventory of city [17]. The consumption-based emission inventory could solve the problem of inflow and outflow data. To provide a method for administrative territorial emission inventory construction of Chinese cities is the primary contribution of our research.

We revised the challenge section and move it to the introduction: "There are some challenges for the compilation of greenhouse gas inventories at the city level. 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 [18, 19]. Commercial activities are much more frequent among cities, compared with inter-provinces / nations, which leads to a great challenge. Second, data for energy consumption and industry products are incomparable and very

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limited for most cities in China [15]. Data used in previous studies are from various sources – including data from city statistical documents, remote sensing images, direct interviews with local governmental officials, and published reports and literature [20]. Those data require systematic reviews for consistency and accuracy.”

As for the yearbooks access mentioned by the reviewer, all the yearbooks can be found and downloaded at China National Knowledge Infrastructure (CNKI) website. CNKI is supported by Education Ministry, Science and Technology Ministry, Propaganda Ministry and General Administration of Press and Publications of China. Therefore, the data downloaded from CNKI is guaranteed. All the yearbooks can be searched at statistical yearbook webpage ([http://oversea.cnki.net/kns55/oldnavi/n\\_Navi.aspx?NavilD=4](http://oversea.cnki.net/kns55/oldnavi/n_Navi.aspx?NavilD=4)). For example, Guangzhou statistical yearbook 2011 used in this study is downloaded from: [http://oversea.cnki.net/kns55/oldnavi/n\\_item.aspx?NavilD=4&BaseID=YKDNA&NaviLink=Search%3a%E5%B9%BF%E5%9A%B0%2fkns55%2foldnavi%2fn\\_list.aspx%3fNavilD%3d4%26Field%3d%25e5%25b9%25b4%25e9%2589%25b4%25e4%25b9](http://oversea.cnki.net/kns55/oldnavi/n_item.aspx?NavilD=4&BaseID=YKDNA&NaviLink=Search%3a%E5%B9%BF%E5%9A%B0%2fkns55%2foldnavi%2fn_list.aspx%3fNavilD%3d4%26Field%3d%25e5%25b9%25b4%25e9%2589%25b4%25e4%25b9)

All the data source of city’s yearbook is given in the Support Information due to the word limitation [21-43]. We have included all data used in the Supporting Information and online at our database: <http://www.ceads.net/city-level-emission-inventory-by-sectoral-approach/> (free to download after registration).

3. The scientific significance Given the lack of the evaluation, validation and traceability, I do not think this study is ready for discussing its scientific significance. The suggested emission mitigation pathways (again, this does not provide direct science implications to atmospheric chemistry/ physics) seem to be a significant contribution to emission management in China, but they were based on the analysis where provinces are used as proxy for cities when deducing information). Given that, I thought the same conclusions could be drawn just looking at province-level data (which are more data rich and consistent than the deduced city data/emissions) instead of trying to obtain emission inventories at challenging city-level using deduced data. Back to the section 2.2 where the authors defined two major challenges in compiling emission inventories for Chinese

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cities (which again I do think those are common issues for any other cities), the real challenge in compiling emission inventories in China is the potential biases that are suggested by the two of the authors of this manuscript. After Guan et al. (2010) and Liu et al. (2015), the science community is also well aware of the bias issue and I thought it is very strange that it was not discussed in this manuscript at all. It is easy to imagine that, given the uncertainty is so large at national and provincial level, it would be extremely challenging to achieve an accurate estimate at city level. If the method proposed in this manuscript is sensitive to the biases suggested by previous papers (I think it is), the method cannot be readily useful for emission management. It was also surprising to me that the word “uncertainty” was never used in this manuscript. Most of emission inventories do not come with uncertainty estimate. However, IPCC methodology does defined two methods (sectoral and reference) to check the validity of emission estimates. Although the use of the two methods would not be able to detect a type of biases suggested by Guan et al. (2010) and Liu et al. (2015), it would be able to check the validity of the emission calculation done as defined. The authors refer to the IPCC methodology many times in the manuscript, but I thought it was very confusing. The method proposed here is not consistent with the IPCC method (this study also used the updated emission factors suggested by Liu et al. 2015). The intention of the use of new emission factors was to obtain accurate emission estimates I believe. Which is totally fine. But in that case, the authors cannot keep consistency with other estimates based on the IPCC method (the authors could say they do not value the consistency). Also, I do not see much value to party follow the IPCC method. The authors could come up with their own best method to obtain the best estimates. I do not see a consistency between the goals of this study and what was done.

RE: Thank you very much for your comment.

Firstly, as we discussed in the paper, cities are the main consumers of energy and emitters of CO<sub>2</sub> throughout the world. Most climate change adaption and CO<sub>2</sub> emission mitigation policies will be implemented at the city level. Emission accounting is the

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basis for any climate policy to be implemented. Research on cities' emission estimation is at the very beginning stage. We attempt to construct cities' emission inventory based on reduced energy balance table. This will fill in the research gap and be helpful and enlightened for future researches. Itself is a scientific contribution already.

Secondly, we add validation (section 3.3) and uncertainty analysis in our revised manuscript (section 4.2). This will be helpful to illustrate the uncertainty range for city's emission accounting.

Lastly, using other emission factors doesn't conflict with IPCC. The emission factors recommended by IPCC are default values for countries which don't have their own special emission factors. Actually, IPCC suggests researchers use emission factors measured based on the specific energy used in specific countries. "Inventory compilers commonly rely on the available literature to find emission factors or other estimation parameters. . . It is good practice, for countries to use their own, peer-reviewed, published literature because this should provide the most accurate representation of their country's practices and activities. If there are no country-specific peer-reviewed studies available, then the inventory compiler can use IPCC default factors. . ." ([44], pp 2.12). So there is no conflict with IPCC to use other emission factors, our results are still keep consistency with IPCC. Lots of previous research are using different emission factors, based on their own experiments or field measurements [45-50].

Liu's emission factors are published in Support Information, which can be downloaded from <http://www.nature.com/nature/journal/v524/n7565/abs/nature14677.html>. Researcher can use the factors. What's more, Liu's emission factors are accepted by National Development and Reform Commission (NDRC) now, and will become the official emission factor of China soon.

Line by line comments P1, L1: As this study only addressed limited aspects of city emission inventory development using so many assumptions, this needs to be more specific defined not to confuse the audience of this manuscript.

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RE: Thank you very much for your suggestion, we have revised the title as “Methods of administrative territorial CO2 emission inventory construction for Chinese cities”.

P1, L19: Even challenging at national level as reported by previous studies. So how would it be possible to get accurate estimates at more challenging scale? Maybe this study is one of the best efforts, but that fact does not support the accuracy of the emission estimates.

RE: Thank you very much for your comment. There may be some uncertainties in our emission estimates, however, this is the most accuracy results we can achieve based on the most comprehensive activity data we can ever find now. Research on cities' emission estimation is at the very beginning stage. We attempt to construct cities' emission inventory based on reduced energy balance table. This will fill in the research gap and be helpful and enlightened for future researches. We add validation (section 3.3.) and uncertainty analysis (section 4.2) in our revised manuscript to improve the accuracy of city's emission estimation in the future.

P1, L21: The authors did use the categories defined in the sectoral approach defined by the IPCC methodology. But it does not have significance if the proposed method yield biased results. Mitigation policy will be done country or local government not globally. It does not make much sense to claim that we need to have the same global standard for city scale issue. The IPCC method has been used to monitor international compliance of reduction of greenhouse gases.

RE: Thank you for your comment. We fully agree with you that mitigation policy should be done country or local government, not globally. That's why we are exploring method to construct cities' emission inventories. Understanding the emission status of cities is the fundamental step for proposing mitigation action.

The current emission inventories of Chinese cities are compiled by sectors, which are not consistent with the national and provincial inventories. The national and provincial inventories are usually compiled according to energy balance tables in China. It's better

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to compile city's inventory in the same way as the national/provincial inventory do (IPCC sectoral approach). This will help the central government, province government, and city government making mitigation policy. That's why we adopt IPCC sectoral approach method.

P1, L23: How accurate those can be if you disaggregate those information?

RE: Thank you for your comment. Actually, we didn't disaggregate the total emission into different sectors/energy types/industry processes. On the contrary, we calculate the CO<sub>2</sub> emissions based on sub-sectors' energy consumption/industrial production. Then we sum up all the emissions from different sectors and energy types to get the total CO<sub>2</sub> emissions for one city. Therefore, there is no uncertainty issues here. Sorry for the misunderstanding.

P1, L27: I agree with this sentence. But I do not think this study has fully achieved it. This study only provides emissions and associated analyses obtained from consistently using their method. I also disagree with the authors claiming "concrete". What was the result that supports the concreteness? I do not see any logical reason that this method outperforms others.

RE: Thank you for your comment. The aim of this study is to develop a methodology for constructing CO<sub>2</sub> 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. We believe our research has strong academic contribution.

Previous emission inventories of Chinese cities are compiled by sectors, which are not consistent with the national and provincial inventories. The national and 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 municipality cities [51, 52] (Beijing, Shanghai, Tianjin, and Chongqing) and few provincial capital cities [20], which have consistent and systematic energy statistics. Our

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newly developed method could compile emission inventory consistently with the national/provincial inventories. Also, our method could be applied to many generic cities, not only for mega cities. This is how our method outperforms others.

We replace the word “concrete” with “feasible” in avoid of misunderstanding.

P2, L51: The method is not shown as concrete. What is this study consistent with?

RE: Thank you for your comment. We replace the word “concrete” with “feasible” in avoid of misunderstanding.

The city emission inventory constructed by our method is consistent with the national/provincial inventories. Previous emission inventories of Chinese cities are compiled by sectors, which are not consistent with the national and provincial inventories. The national and provincial inventories are usually compiled according to energy balance tables in China. Our newly developed method could compile emission inventory consistently with the national/provincial inventories.

P3, L3: The uncertainty is relatively new discussion in this topic, but emission inventory has been important for many years.

RE: Thank you for your comment. We added “uncertainty analysis” in section 4.2 in the revised manuscript.

“Analysing uncertainty is an important tool for improving emission inventories that contain uncertainty [4, 5]. Different methods are used to analyse the uncertainty of emissions, Jonas et al. [6] describe four relevant uncertainty terms and six techniques that can be used to analyse uncertain emission changes. In this study, we employ Monte Carlo simulations to calculate the uncertainties of 20 Chinese cities’ CO<sub>2</sub> emissions, which is recommended by IPCC [7] and widely used in previous research [8].

As the CO<sub>2</sub> emission is calculated as product of activity data and emission factors, therefore uncertainty comes from two parts: activity data (fossil fuel consumption) and emission factors. According to Monte Carlo analysis, we should assume individual

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probability density functions for the two variables firstly, then simulate the CO<sub>2</sub> emissions values with the assumed functions for many times [9]. Industrial processes emit much less CO<sub>2</sub> (9.89% of the total CO<sub>2</sub> emissions) compared with fossil fuel combustion. What's more, emissions from industrial process are generally with less uncertainties [10, 11]. Therefore, we only consider uncertainty from fossil fuel consumption in this study. We calculate the uncertainty of both the overall CO<sub>2</sub> emissions and sub-sectors' emissions of the 24 city cases in this study.

We assume normal distributions for both activity data and emission factors [10, 11]. The coefficients of variation (CV, the standard deviation divided by the mean) of different emission factors and fossil fuel consumptions are chosen from previous literatures, see Table 3. We repeat the simulation procedure for 20,000 times in Monte Carlo analysis. Table 4 shows the total uncertainties of 24 cities' emissions in 2010 with 95% Confidence Interval.

The average uncertainty of total CO<sub>2</sub> emissions of the 24 case cities is from -4.08% to 4.09%, falling in the range of 10% to 20% for non-OECD countries [12, 13]. This illustrates that our estimations are relatively accurate and realizable. Among the 24 cities, CO<sub>2</sub> emissions of Shenzhen have the smallest uncertainty (-1.72%, 1.70%), while emissions of Jixi have the highest uncertainty (-5.84%, 5.79%). As the largest contributor of CO<sub>2</sub> emissions (39.19% of the total emissions averagely of the 24 cities in this study), the emissions from electricity generation sector has the largest uncertainty averagely (-5.70%, 5.75%) among different sectors. This is caused by large amount of coal combusted in coal-fired power plant, uncertainty of coal's emission factor is the highest among energy types, despite the fossil fuel consumption in electricity generation sector has a low uncertainty. In contrast to power plant, CO<sub>2</sub> emission from service sector (transportation and territorial industries) have the lowest uncertainty averagely (-1.87%, 1.88%). Much oil and gas are used in these sectors compared with power plant, which have lower uncertainties of emission factor. Detailed uncertainties by sectors are shown in SI Table S9."

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P3, 59: I believe some inventories are at least partly based on state level information.

RE: Thank you for your comment. We supplied the reference of state/province level emission research.

“Most of the previous emissions inventories were developed at the national level [53-61], provincial level [14, 62-65], and sectoral level [66-69] and for specific fossil fuel combustion emission sources [70, 71]. Emission inventories for cities are limited [17, 20, 72-78].”

P4, L97: These challenges are common for all cities almost. The real challenges specifically for China is the potential biases recently reported. I do not think the use of territorial emission approach mitigates the inflow/outflow issue in emission development. It is a data problem and there are not enough data to overcome. I do not think the data availability cannot be mitigated by deducing information from limited data. The authors are compromising instead of mitigating and the validity needs to be shown.

RE: Thank you for your comment. It's true that the challenges are common for all cities. The production-based emission inventory constructed in this research (adopting the IPCC administrative territorial scope) doesn't involve the inflow/outflow issue among cities. By using our production-based emission inventory and economic models, further research could estimate the consumption-based emission inventory of city. The consumption-based emission inventory could solve the problem of inflow and outflow data[17]. To provide a method for administrative territorial emission inventory construction of Chinese cities is the primary contribution of our research.

We revised the challenge section and move it to the introduction: “There are some challenges for the compilation of greenhouse gas inventories at the city level for China. 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 [18, 19]. Commercial activities are much more frequent among cities, compared with inter-provinces / nations, which leads to a great

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challenge. Second, data for energy consumption and industry products are incomparable and very limited for most cities in China [15]. Data used in previous studies are from various sources – including data from city statistical documents, remote sensing images, direct interviews with local governmental officials, and published reports and literature [20]. Those data require systematic reviews for consistency and accuracy.”

P5, L121 Why did the authors think this calculation is superior?

RE: This calculation method is recommended by IPCC and widely used globally, including China. The national and provincial inventories are almost all compiled in this way (i.e., according to energy balance tables in China) [79, 80]. However, the current emission inventories of Chinese cities are compiled by sectors, which are not consistent with the national and provincial inventories. In this study, we develop a feasible methodology for constructing CO<sub>2</sub> emissions inventories for Chinese cities based on energy balance table, aiming at providing unified and comparable energy and emission statistics for generic Chinese cities. We have addressed this in introduction and literature review section.

“In this study, we develop a feasible methodology for constructing CO<sub>2</sub> 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 [10, 14-16]. 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 CO<sub>2</sub> 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

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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.”

P5, L140: It is great to have detailed information, but the significant amount of information were created based on assumption w/o any evaluation.

RE: Thank you for your comment. Actually, we didn't disaggregate the total emission into different sectors/energy types/industry processes. Indeed, we calculate the CO2 emissions based on sub-sectors' energy consumption/industrial production. Then we sum up all the emissions from different sectors and energy types to get the total CO2 emissions for one city. Therefore, there is no uncertainty issues here. Sorry for the misunderstanding.

We have include all data used in the Supporting Information and online at our database: <http://www.ceads.net/city-level-emission-inventory-by-sectoral-approach/> (free to download after registration).

P5, L131: This was not clear to me. The import/export info is not fully available. If so, how did the author exclude the portion? And this issue is not just for electricity. There should be cars and airplanes going in and out for example.

RE: Thank you for your comment. Firstly, we are calculating the administrative territory emissions, which only include emission induced within the city boundary. The situation of transportation going in and out are not considered in this study. We calculated the CO2 emissions based on the city's energy statistics. For example, one car refuels in city A and goes to city B. The CO2 emission are counted to city A since the energy are calculated in city A.

As for the electricity and heat, we calculate the CO2 emissions from the generation side, instead of the consumption side. For example, we estimate how much CO2 are

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emitted from the fire-power plant when burning coal to generate electricity/heat. In this way, we only include emissions from electricity/heat generated within the city boundary and exclude the import portion. This conform to administrative territorial scope. We rewrite the scope definition section in the revised manuscript for clearer understanding.

“First, we calculate the emissions from fossil fuel combustion. The emissions are calculated for 20 energy types and 47 socioeconomic sectors. The 47 socioeconomic sectors are defined according to the Chinese National Administration for Quality Supervision and Inspection and Quarantine [81], which include all possible socioeconomic activities conducted in a Chinese city’s administrative boundary (shown in SI Table S2). We include 20 energy types in this paper that are widely used in the Chinese energy system (see SI Table S3) [82].

Energy used as chemical raw material and loss during transportation are removed from the total energy consumption in order to avoid double counting. Emissions from electricity and heat generated within the city boundary are counted based on the primary energy input usage, such as raw coal [83]. 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.

In the second part, we calculate CO<sub>2</sub> emissions from 9 industrial production processes (see SI Table S4). The industrial process emissions are CO<sub>2</sub> emitted as a result of chemical reactions in the production process, not as a result of the energy used by industry. Emissions from industrial processes are factored into the corresponding industrial sectors in the final emissions inventory.

By including the emissions from industrial processes, the emissions inventory designed in this paper includes all administrative boundary territorial CO<sub>2</sub> emissions from 47 sectors, 20 energy types and 9 main industrial processes.

We adopt the IPCC sectoral approach [7] to calculate the CO<sub>2</sub> emissions, which is

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widely applied by research institutions and scholars [84-92]. CO<sub>2</sub> emission equals to activity data (fossil fuel consumption / industrial products' production) times emission factor. Detailed CO<sub>2</sub> emission calculation method from IPCC are shown in SI."

Detailed explanations are also shown in Support information as well.

P6, L148: Data source please. Enough information was not given to us to keep track of what the authors did in this study.

RE: Thank you for your comment. We cited the reference with this sentence. (Department of Energy Statistics of National Bureau of Statistics of the People's Republic of China, 1986-2013)

P6, L163: The disaggregation should also introduce errors/uncertainties. This study implicitly assumed the disaggregation introduces zero errors. An assessment should have been done.

RE: Thank you for your comment. Actually, we didn't disaggregate the total emission into different sectors/energy types/industry processes. On the contrary, we calculate the CO<sub>2</sub> emissions based on sub-sectors' energy consumption/industrial production. Then we sum up all the emissions from different sectors and energy types to get the total CO<sub>2</sub> emissions for one city. Therefore, there is no uncertainty issues here. Sorry for the misunderstanding.

P7, L180: Again, the data availability cannot be mitigated by deducing information from limited data. If the authors think it is possible, the authors needed to show why it is possible by showing results.

RE: Thank you very much for your comment. We do agree that there are some uncertainties in our emission estimates, however, this is the most accuracy results we can achieve based on the most comprehensive activity data we can ever find now. Research on cities' emission estimation is at the very beginning stage. It's quite necessary to estimate the cities' emission inventories with the current poor data. It's the

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basis of any further research.

To evaluate the uncertainties, we add “validation” and “uncertainty analysis” in section 3.3 and 4.2 in our revised manuscript. This will be helpful to improve the accuracy of city’s emission estimation in the future.

P7, L182: Emission inventories are developed using different deduction methods (see Table S4). I am not sure the emission estimates can be treated without uncertainty estimates. I would hesitate to call city emission estimates obtained using different deduction methods as consistent estimates.

RE: Thank you very much for your comment. The emission inventories of different cases are constructed in the same method, which is based on energy balance table and recommended by IPCC [7, 83]. We only deduce the energy activity data with different methods. We added “validation” and “uncertainty analysis” in section 3.3 and 4.2 in our revised manuscript.

P10, L257: I am very confused by section 3.6. If the IPCC methodology is emphasized, the authors should used the emission factors defined by the IPCC. Although the paper by Liu et al. (2015) was published, I believe emission factors reported in the paper were not published yet and thus IPCC (and the scientific community) cannot use them. The use of IPCC emission factors might yield biased estimates. However, it will give a compatibility with other emission estimates obtained using the IPCC method and traceability. If the authors would like to obtain accurate emission estimates, the authors would not have to do follow the IPCC method and came up with own procedure to get the best estimates. I was not clear what the authors would like to achieve through this study. I did not see consistency between the goals of this study and what was done.

RE: Thank you very much for your comment. Using other emission factors doesn’t conflict with IPCC methodology.

The emission factors recommended by IPCC are default values for countries which

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don't have their own special emission factors. Therefore, the emission factors given by IPCC is not so accurate for China. IPCC suggests researchers use emission factors measured based on the specific energy used in specific countries[44] (see response to general question 3 above). There is no conflict with IPCC to use other emission factors, our results are still keep consistency with IPCC. Lots of previous research are using different emission factors, based on their own experiments or field measurements [45-50].

The emission factors published in Liu's paper are measured based 602 coal samples from the 100 largest coal-mining areas in China, which are assumed to be more accurate for China. Liu's emission factors are published in Support Information, which can be downloaded from <http://www.nature.com/nature/journal/v524/n7565/abs/nature14677.html>. Researcher can use the factors. What's more, Liu's emission factors are accepted by National Development and Reform Commission (NDRC) now, and will become the official emission factor of China soon.

P11, L282: What do you mean by "different developmental stages"? How are they different?

RE: Thank you very much for your comment. When we say the cities are in different development stages, we actually mean the cities are in different sociometric development stages with different indexes, such as population, per capita GDP.

"In this paper, we apply our method to 24 case cities and compile the CO2 emissions inventory for 2010. These 24 cities, which cover all the possible situations for data collection cases discussed above, are in different sociometric developmental stages. Per capita GDP of the 24 cities varies from 14.80 thousand Chinese Yuan (Zunyi) to 106.88 thousand (Shenzhen). 9 of the 24 case cities are provincial capital cities, which are larger and more affluent than the other 15 non-capital cities generally. Table 2 shows socioeconomic indexes of the 24 case cities."

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P11, L285: 2011 statistical yearbook. Data source please.

RE: Thank you for your comment. The data source is given in the Support Information due to the word limitation [21-43].

P14, L386: The use of the word “consistent” here is very misleading. This method is not fully consistent with IPCC method. Emission inventories from Chinese cities are estimated using different methodology based on the data availability. I do not know if that was consistent. The author did not provide any uncertainty quantification and we do not even know how to consistently compare emissions from different cities (which are estimated from different method). I do not see any consistent way presented in this study.

RE: Thank you for your comment.

Firstly, we argue that our method is consistent with IPCC method. We are using IPCC calculation method, IPCC administrative territorial scope. As for the emission factors, the emission factors recommended by IPCC are default values for countries which don't have their own special emission factors. The emission factors given by IPCC is not so accurate for China. IPCC suggests researchers use emission factors measured based on the specific energy used in specific countries. So there is no conflict with IPCC to use other emission factors, our results are still keep consistency with IPCC. Lots of previous research are using different emission factors, based on their own experiments or field measurements [45-50].

Secondly, 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. The most important thing is that 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

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emission research calculated by sectors.

Thirdly, we added “validation” and “uncertainty analysis” in section 3.3 and 4.2 in the revised manuscript. This will be helpful to compare emissions from different cities and improve the accuracy of city’s emission estimation in the future.

P14, L387: Yes, but limited to people who understand Chinese. I was not able to get any one of city-level yearbook (so I acknowledge that this review was not fully completed by the fact too). In reality, people don’t need to calculate the emission inventory individually if the government provides one. The community just needs an emission inventory with rigorous uncertainty estimates and traceability.

RE: Thank you for your comment. The access to Chinese city-level yearbook is discussed above in the general comments. The government only provide national and provincial energy inventory in China. Our previous research has been able to construct emission inventory for China and its provinces [10, 14-16]. Now, we are tackling the city level emission inventory which government does not provide at all. City level emission estimation is a more complex and less data available. We develop this method and utilize currently available energy data to construct emission inventory (which will benefit academic users). Itself is a scientific contribution already.

We have include all data used in the Supporting Information and online at our database: <http://www.ceads.net/city-level-emission-inventory-by-sectoral-approach/> (free to download after registration).

P14, L391: The use of the word “representative” is also misleading. These 20 cities were mainly chosen to present a possible case of scenarios that affect on the results of this method (see P11, L282). Beijing, and Shanghai were not included while the authors claimed the representative 20 cities.

RE: Thank you for your comment. We added another 4 case cities in this study. The 24 case cities could make the research more substantial. It’s true that the 24 case cities

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are chosen to present all the possible case of scenarios developed in our method. That's why we consider them as "representative". We have removed the word "representative" to avoid misunderstanding.

As the aim of our research is developing a feasible inventory construction methodology for other generic Chinese cities. Emissions of mega cities like Beijing, Shanghai, which have consistent and systematic energy statistics, has been research clearly in previous studies [20] [51, 52]. Therefore, we didn't include them in our study.

P15, L396: (Assuming the emissions are all validated). This is a good insight for emission managements. But I am not sure if ACP is the best place to discuss.

RE: Thank you for your comment. The relevance to ACP is discussed above in the general comments.

P15, L400: Some efforts – for example?

RE: Thank you for your comment. We expand the policy recommendation section.

"Coal combustion emits more CO<sub>2</sub> 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 [93]. 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 [94]. 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

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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 [95, 96].”

P15, L411: How do you reform the industrial structure?

RE: Thank you for your comment. We expand the policy recommendation section.

“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 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.”

P15, L412: These are again from 20 cities selected for these cities, and do not the best representative of Chinese 30 cities (it should have megacities too). So I am not sure if it is fair to draw a general conclusion from the results from this study (again, there is no evaluation/uncertainty quantification/validation)

RE: Thank you for your comment. We added another 4 case cities in this study. The 24 case cities could make the research more substantial. As most existing research fo-

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cused on a few specific megacities, such as municipality cities [51, 52] (Beijing, Shanghai, Tianjin, Chongqing) and few provincial capital cities [20], which have consistent and systematic energy statistics, the aim of our research is developing a feasible and consistent inventory construction methodology for other generic Chinese cities. So we don't include megacities (Beijing, Shanghai), but we do include some provincial capital city such as Hefei, Guangzhou, Nanning, Changsha, Xi'an, Chengdu. These cities are also megacities, especially Guangzhou and Shenzhen.

P15, L419: As mentioned above, these limitations are very critical to conclude this study. I would not recommend this manuscript for publication (even as a technical report) before addressing these.

RE: Thank you for your comment. There may be some limitation in our estimation, however, this is the most accuracy results we can achieve based on the most comprehensive activity data we can ever find now. Research on cities' emission estimation is at the very beginning stage. We attempt to construct cities' emission inventory based on reduced energy balance table. This will fill in the research gap and be helpful and enlightened for future researches.

L15, P421: How could the authors do that? It is not consistent. There is no supporting information for this statement.

RE: Thank you for your comment. 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.

Restrained by the poor data quality at city-level, we can only develop different method to reduce the data to meet the data requirement of emission inventory construction. It's true that there are some limitation and uncertainties in our emission estimates, however, this is the most accuracy results we can achieve based on the most comprehensive activity data we can ever find now. Research on cities' emission estimation is

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at the very beginning stage. We attempt to construct cities' emission inventory based on reduced energy balance table. This will fill in the research gap and be helpful and enlightened for future researches.

L15, P422: I am not sure how to respond to this sentence.

RE: Thank you for your comment.

L15, P423: We do not know how accurately emissions are calculated even in this study. Then how do we know an improvement in emission estimates?

RE: Thank you for your comment. We add "validation" and "uncertainty analysis" in our revised manuscript (section 3.3 and 4.2). This will be helpful to improve the accuracy of city's emission estimation in the future.

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<http://www.atmos-chem-phys-discuss.net/acp-2016-176/acp-2016-176-AC1-supplement.pdf>

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Interactive comment on Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2016-176, 2016.

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