

Responses to Anonymous Referee #2:

The manuscript presents a well-designed analysis of questions related to Chinese pollution intensity, as it captures the reader's attention from the introduction. The description of the environmental situation in China, linked to its social and economic consequences, is a perfect starting point when we talk about the Asian giant. The paper provides the scientific community with more evidences, for a better and deeper analysis about the reasons behind the rise of China as the biggest pollutant in recent years. It is easy to identify similar papers that try to contribute to this open debate. In this sense, and as a researcher in the study of international responsibility criteria (producer, consumer or shared), I regard the proposal by the authors as very interesting. The questions tackled in the paper can be likened to some of the consequences of developed countries signing of the Kyoto Protocol for emerging economies like, for example, China. This paper presents the global Chinese environmental situation, understood as the increase in global emissions due to the presence of highly pollutant production processes in emerging regions (rather than countries) inside China. Rich regions (such as the coastal areas) could represent those developed countries that have implemented more and more restricted environmental and energy policies in recent years. Those regions/countries, by means of offshoring processes to other regions/countries with weaker environmental policies, have avoided territorial or producer responsibility for emissions (as accounted under the Kyoto Protocol), but have caused, supposedly, an increase of Chinese/global emissions. From my point of view, the identification of the question, the relation to social and economic costs, and the characterization of some policy implications, are the most interesting contributions of the paper. The model proposed is not new, as the consumption-based approach in a MRIO framework is a well-recognized model. However, the selection of the air pollutants and the detailed analysis of the Chinese interregional trade relationships, also provides the scientific community with useful tools and evidences. In this sense, I would say that the paper could had been a little bit more ambitious, once the scope is presented and the implications and objectives are defined. Some of these ideas are commented in the next section.

Responses: We appreciate for the encouraging comments from the reviewer, which enhanced our confidence in the contribution of this work to the scientific community. We further emphasized the objective and implication of this work in the abstract, introduction, and conclusions of the revised manuscript. We clearly stated that this work is the first study which quantified consumption-based air pollutant emissions for each province in China and tracked virtual emission flows of air pollutants embodied in China's interprovincial trade. As pointed out by the reviewer, the results from this work could help to better understand the responsibility for air pollutant emissions in China, and further evaluate the potential health impact of trade activities by using chemical transport models. We also thank the reviewer for the specific suggestions, which are addressed below.

Related to the allocation criterion chosen in this paper (the consumption-based

perspective): It would have been interesting to prove or, at the very least, to cite the implications of the implementation of other criteria based on sharing emissions between agents. The application of a shared responsibility criterion like the one proposed by Lenzen and Gallego (2005), Cadarso et al. (2012) or Hoekstra and Wiedmann (2014) could help northern and central Chinese regions to assume the increase of costs derived from mitigation policies. Sharing emissions between agents participating in the pollutant activity could contribute to a better solution of the problem as producers and consumers are both involved in emissions reduction.

Responses: Many thanks for the insightful suggestion. In response to this comment, we added following discussion in the conclusion section of the revised manuscript. “It should be noted that although the results derived from this work could help the policy makers to better understand the responsibility of pollution from consumption perspective, splitting the share of responsibility between producers and consumers is more complicated as producers also gain economic benefit when emitting pollutants (Barrett et al., 2013). Application of shared responsibility criterion (e.g., Gallego and Lenzen, 2005; Cadarso et al., 2012; Hoekstra and Wiedmann, 2014) which involves both producers and consumers in emission reduction could help developing provinces in China to assume the increase of costs derived from mitigation policies and contribute to a better solution of the problem.”

Eco-Labels: The introduction of an Eco-Labeling system could be another alternative, looking for incentives to improve the efficiency of both existing and new technologies not only from the perspective of technology transfer, but also involving consumers and their decisions. In this case, the consideration of global production chains implies some limitations. O’Rourke (2014) highlights some of them: limitations on sustainability measurements of the supply chains, limitations of data supplied to decisions-makers (consistent and proved models) or disincentives for firms to pay the full costs of supply chains (key limitation). The third point is the most relevant as firms are the agents that decide to outsource their production chains. The implication of firms assuming their share of responsibility is needed, following the line presented in Skelton (2014), already quoted by the authors, or in the control criterion proposed by López et al. (2014).

Response: We agree. We have revised the manuscript (in Sect. 4.2) according to the suggestion, as follows: “Economic stimulus or penalty instigated by leading companies can help reduce the emissions of its suppliers more effectively as companies are the agents that decide to outsource their production chains (O’Rourke, 2014), thus can exerting a cleaning effect on its upstream supply chains more easily (Skelton, 2013). Eco-Labeling system could achieve efficiency gains by producers which can be monitored by regulative bodies. Consumer choices in eco-labelling can be a great incentive for companies to adopt such scheme in order to promote market competitiveness (Grundey and Zaharia, 2008).”

Emissions Trading Scheme: Another potential improvement for the paper could have been to take into account or at least cite the Chinese Emissions Trading Scheme (ETS),

similar to the European Union Trading System, that is currently under evaluation in China (Guan et al. 2014). Like Barrett et al. (2014) suggest, and given the consumer orientation of the paper, the future evaluation of this ETS under the consumer perspective could be interesting.

Response: Thanks for the suggestion. We have added the following sentence in the revised manuscript: “*The pilot phase of China’s Emissions Trading Scheme (ETS) on CO₂, SO₂, and NO_x has proven its effectiveness in emission reductions, expanding the ETS system across China can be used to mitigate air pollutant emissions*”.

Technology transfer: From my point of view, the technology transfer is not the only option that can contribute to solve the problem. The establishment by policy makers of some limitations to specific new installations which exceed a fixed benchmarking could also be part of the solution. There are some examples for the European Union. The case of the restriction to the use of coal in electricity generation in Spain and some European Union countries is an example (Zafrilla 2014).

Response: Thanks for the suggestion. In the revised manuscript, we revised the statement as below: “*Technology transfer between developed and developing regions should play a leading role in joint actions for regional or interregional air pollution control. For developed regions, industrial transfer should be accompanied by technology transfer; for less developing regions, higher emission standard should be established for new installations that exceed a fixed benchmarking, thus reducing the increment of emissions.*”

Taxes: Another interesting solution or alternative could be the transfer of environmental impacts to consumers via environmental taxation. Consumers can guide the economy to a sustainable path changing their consumption patterns. In the case of one country (China), it is possible to highlight some advantages of the establishment of those taxes for international trade. Trade wars are not possible between regions after the implementation of the tax. And there is no risk of carbon leakage as only one government designs, collects and redistributes the environmental tax.

Response: Thanks for the insightful suggestion. We have added the discussion on environmental tax in Sect. 4.2 of the revised manuscript. *Although China has achieved great progress in technology improvements and pollution intensity reduction, total emissions are still on the rise as improvements in technology efficiency were offset by increasing consumptions (Liang et al., 2014; Guan et al., 2014). Taxes can be used to transfer environmental impacts to consumers, thus reduce the consumption volume and related emissions.*

Pollution haven hypothesis: After reading the paper, the reader could conclude that the pollution haven hypothesis (PHH) exists among Chinese regions due to the differences between their pollution intensities. Nevertheless, and following Zhang et al. (2014), this evidence is not proved for CO₂ emissions; in fact, they find the opposite. The estimation of the Balance of Avoided Emissions (BAE) shows an almost

negligible positive figure (PHH) for the electricity sector. For the whole economy, the sign of the BAE is negative, as a consequence of the industrial relocation to inland provinces. This result shows that there are not relevant differences in pollution structures between Chinese regions. The relocation of parts of the production chains does not imply an increase in emissions. Understanding this, the most interesting conclusion of this paper should be the evaluation of how location, concentration and subsequent atmospheric transportation of pollutant particulates affect health. A potential extension using an Atmospheric Chemical Transport model would improve the usefulness of the paper.

Response: Unlike CO₂, emission intensity of air pollutants in developing regions are much higher than that in developed regions due to lack of emission control measures (e.g., desulfurization devices). Outsourcing air pollutant emissions within China could result in an increase of total emissions. Emission transfer of air pollutants due to the redistribution in emissions could have potential significant effects on regional air quality. However, as pointed out by referee #3, the impact of emission transfer on human health could be negative or positive, because emissions may transfer to regions with better dispersion conditions or less population. We have clarified this point in the revised manuscript. Investigating the air pollution and health impact caused by cross-regional industry transfer is a very interesting and important topic, but we believe that it is beyond the scope of current paper. The consumption-based emission inventory developed in this work has provided a good basis for consumption-based health benefit evaluation, and we will extend this work in the future.

References:

- Barrett, J., Peters, G., Wiedmann, T., Scott, K., Lenzen, M., Roelich, K., and Le Quéré, C.: Consumption-based GHG emission accounting: a UK case study, *Clim. Policy*, 13, 451-470, doi:10.1080/14693062.2013.788858, 2013.
- Cadarso, M.-Á., López, L.-A., Gómez, N., and Tobarra, M.-Á.: International trade and shared environmental responsibility by sector. An application to the Spanish economy, *Ecol. Econ.*, 83, 221-235, doi:10.1016/j.ecolecon.2012.05.009, 2012.
- Gallego, B., and Lenzen, M.: A consistent input–output formulation of shared producer and consumer responsibility, *Econ. Syst. Res.*, 17, 365-391, doi: 10.1080/09535310500283492, 2005.
- Grundey, D., and Zaharia, R. M.: Sustainable incentives in marketing and strategic greening: The cases of Lithuania and Romania, *Ukio Technologinis ir Ekonominis Vystymas*, 14, 130-143, doi:10.3846/1392-8619.2008.14.130-143, 2008.
- Guan, D., Hubacek, K., Tillotson, M., Zhao, H., Liu, W., Liu, Z., and Liang, S.: Lifting China's Water Spell, *Environ. Sci. Tec.*, 48, 11048-11056, doi:10.1021/es501379n, 2014.
- Hoekstra, A. Y., and Wiedmann, T: Humanity's unsustainable environmental footprint, *Science*, 344, 1114-1117, 2014.
- Liang, S., Liu, Z., Crawford-Brown, D., Wang, Y., and Xu, M.: Decoupling analysis

and socioeconomic drivers of environmental pressure in China, *Environ. Sci. Tec.*,48,1103-1113,doi: 10.1021/es4042429, 2014.

O'Rourke, D.: The science of sustainable supply chains, *Science*, 344, 1124-1127, 10.1126/science.1248526, 2014.

Skelton, A.: EU corporate action as a driver for global emissions abatement: A structural analysis of EU international supply chain carbon dioxide emissions, *Global Environ. Change*, 23, 1795-1806, doi:10.1016/j.gloenvcha.2013.07.024, 2013.