Assessment of carbon emission in China and factors influencing the estimation: an input-output analysis

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Abstract. We used the input-output method to analysis the impact of four factors on carbon dioxide emission calculations. These factors included the transformational energy, energy invested in the gross capital formation, energy exported or transferred, and the carbon emission from cement production. In detail, if the transformational energy segment was not removed, the carbon dioxide emission from the intermediate demand was 0.16% higher than the baseline scenario, and 4.17% lower than the baseline scenario in the final demand. If the energy invested in the gross capital formation was not considered, the carbon dioxide emission from the intermediate demand was 1.38% higher than the baseline scenario and 35.71% lower than the baseline scenario from the final demand. If the energy exported and transferred was not considered, the carbon dioxide emission from intermediate demand was 1.02% higher than the baseline scenario, and 26.35% lower than the baseline scenario from the final demand. If the carbon emission from the cement production was not included, the carbon dioxide emission from the intermediate demand was 10.63% higher than the baseline scenario, and 10.23% lower than the baseline scenario from the final demand. Finally, we propose policy recommendations in terms of choosing carbon emission calculation methods.

1. Introduction
At the advent of the 21st century, the greenhouse effect caused by excessive carbon dioxide emission has become notably prominent. Consequently, in order to protect the ecological environment and alleviate the greenhouse effect, it is inevitable to control the current excessive carbon dioxide emission. One of the most critical step in the controlling strategy is the calculation of the emission, since the results of this calculations not only serve as a reference to judge the performance of the governmental emission reduction schemes but also affects the degree of China's emission reduction efforts and the proportion of China’s international carbon emission responsibility. Currently, there are three mainstream methods for calculating carbon emissions: energy consumption, life cycle assessment, and input-output method. The energy consumption method refers to carbon emissions caused by energy combustion, such as Costa [1]. Yao et al. [2] applied this method to study energy consumption and carbon emissions of rural residential buildings in China. The study found that the energy consumption of rural residential buildings has shown a significant shift from non-commercial energy to commercial energy. The proportion of biomass energy consumption declined from 81.5% in 2001 to 70.9% in 2008, and the proportion of commercial energy consumption rose from 17.1% to 25.1%. At the same time, the total carbon dioxide emissions from rural residential...
energy consumption increased significantly from 152.2 million tons in 2001 to 283.6 million tons in 2008. Considering the necessity of mitigating GHG emission and energy consumption, Wu et al. [3] proposed a context-dependent DEA technique to allocate China’s national carbon dioxide emissions and energy intensity reduction targets. Sumabat et al. [4] used energy consumption to study fuel combustion and carbon dioxide emissions in the Philippines. Xu and Tao [5] calculated the energy consumption of power generation by using the energy consumption method and decomposed the carbon intensity in China’s power production.

Life Cycle Assessment (LCA), which had its beginnings in the 1960’s, is a method for integral assessment of environmental impacts (e.g., climate change, eutrophication, etc.) along the life cycle of a product. Liu et al. [6] performed a Life Cycle Assessment to analyze the environmental consequences of fossil energy use and greenhouse gas emission in different pear production chains in China. Zhao et al. [7] used the LCA to analysis the energy demand and greenhouse gas emissions of four propylene production pathways in China. In a production system, Cao et al. [8] used the LCA to verify that reducing machine carbon emissions is the key to achieving low carbon manufacturing in a variety of manufacturing system environments. Example analysis showed that lightweight design and remanufacturing could reduce fixed emissions by increasing energy efficiency, enabling equipment and production. Rajaeeifar et al. [9] used this method to investigate energy, economic flows and greenhouse gas emissions from Iranian olive oil production. Results revealed that the total energy consumption through the olive oil life cycle was 20344 MJ ha⁻¹ while the mass-based allocation method results indicated that the total energy consumption was 8035 MJ ha⁻¹. Peng [10] used the LCA to study carbon emissions in the construction industry, and these findings indicated that governments could achieve the greatest reductions in carbon emissions by targeting the operational phase of buildings. Yang et al. [11] used the LCA to study on carbon footprint accounting for a residential building in China, and the results showed that the carbon footprint of the building is 2993 kg CO₂eq/m². The operation phase contributed to 69% of the total greenhouse gas emission, while the building material production contributed to 24%. Concrete was the most used building material, which accounted for 82% of mass but contributed to only 44% of the material related greenhouse gas emissions.

The input-output method is a table of input and output in which a series of internal departments are arranged in a certain period. When using the input-output method to solve carbon emissions, direct and indirect emissions of carbon dioxide are estimated based on the direct consumption coefficient of the product and the complete consumption coefficient. Some literature pays attention to carbon emissions from energy consumption directly in the production process, ignoring energy consumption and thus embodied carbon emissions of the other products consumed as intermediate inputs, such as Zhang et al. [14]. Lin and Xie [15] used this model to analysis carbon emissions of China’s food industry. The results showed that changes in carbon emissions in the food industry mainly depended on total output effect and energy intensity effect, and energy intensity effect was the most important factor reducing carbon emissions. Su et al. [16] analyzed the city state's carbon emissions from the demand perspective using the input-output method and investigated the drivers of emission changes using structural decomposition analysis. The results showed that exports accounted for nearly two-thirds of its total emissions and growth in its emissions in the last decade was largely export-driven. Long and Yoshida [17] applied the input-output table of Tokyo to evaluate energy consumption at the city scale. Pan et al. [18] used the input-output method to analyze the driving factors of carbon dioxide emissions in atypical large cities. The results showed that national strategy had a noticeable impact on the regional economy while changing the patterns of carbon emissions in China: carbon emissions were most prominent in economic zones, and inter-regional carbon flows became more active and more balanced. The advantage of the input-output method is that it can carry out implicit carbon dioxide emissions, but the deficiency is that the calculation results are not as accurate as others methods.

There are many different methods for calculating the carbon dioxide emission, and they are all their own merits and demerits. In this study, initially, by using the energy consumption method, we calculated the carbon energy emission; subsequently, we investigated four major influencing factors of carbon dioxide emission calculation, namely, transformational energy, energy invested in gross capital
formation, energy exported and transferred, and carbon emission from cement production. Through an input-output method, we quantitatively analyzed the impact of these four factors on the carbon dioxide emission calculation and obtained the deviations in the calculation while adjusting them.

2. Data and model
Carbon dioxide emission mainly includes two parts, carbon dioxide emission from energy combustion and the one from cement production.

2.1. Data
In this work, we performed a case study using China's carbon dioxide emission in 2012, as this is the latest annual input-output data available from the China Statistical Yearbook-2015. Other major data sources for this study included the China energy statistical Yearbook-2013, from which we obtained the average lower heating value of each energy resource and the carbon emission coefficients (the amount of carbon dioxide emitted per unit of fuel consumed). We also obtained data of the national cement production and the related carbon dioxide emission coefficient that was employed in this study.

2.2. Method
2.2.1. Carbon dioxide emission from energy combustion. The carbon dioxide emission from energy combustion is mainly calculated by the energy consumption, and the carbon dioxide emission of an individual industry is mainly derived by decomposing the total amount of carbon dioxide emission from energy combustion according to its proportion of energy consumption. Due to the wide variety of energy sources (20 energy sources listed in the China Energy Balance Sheet-2012), the total amount of CO₂ emission from energy combustion should be the sum of CO₂ emission from the combustion of each energy source, which can be computed as:

\[ E = \sum_{i} E_{i} = \sum_{i} C_{i} \times W_{i} \]  

(1)

According to the Energy Balance Sheet, the segment of the energy used for combustion includes the final consumption of energy, the consumption for thermal power generation, and the consumption for heating, but excluding the part used as raw materials in the industry, and is computed as:

\[ C_{i} = C_{i}^{T} + C_{i}^{P} + C_{i}^{H} - C_{i}^{M} \]  

(2)

The carbon dioxide emission coefficient of energy combustion is computed by using the average lower heating value and the carbon dioxide emission coefficient per unit heat. If the carbon dioxide emission coefficient of each heating unit generated from energy combustion and the average lower heating value (i.e., the heat generated from per unit energy in the combustion process) of each energy source is known, the carbon dioxide emission coefficient of energy combustion (i.e., the carbon dioxide emission from per unit energy in the combustion process) can be obtained by multiplying these two together, and the coefficient of each energy source can be computed as:

\[ W_{i} = T_{i} \times Q_{i} \]  

(3)

In this study, we discuss the situations where these three parts of energy consumption are subtracted or not. First, without subtracting any of these three parts of energy consumption, the total energy investment for the combustion of all energy industries is:

\[ D_{j} = DI_{j} + DF_{j} \]  

(4)

where, \( D_{j} \) is the total energy investment for the combustion of energy industry \( j \); \( DI_{j} \) is the energy from the intermediate demand for the combustion of energy industry \( j \); \( DF_{j} \) is the energy from the final demand for the combustion of energy industry \( j \). If all there three parts are subtracted, then the \( D_{j} \) is:
\[ D_j = DI_j + DF_j - DC_j - DE_j - DS_j \]  

(5)

where, \( DC_j \) is the energy formed into total fixed capital; \( DE_j \) is the energy which has been exported or transferred; \( DS_j \) is the transformational energy generated from energy industry \( j \). Then, the carbon dioxide emission coefficient of an energy industry is:

\[ e_j = \frac{E_j}{D_j} \]  

(6)

where, \( e_j \) is the carbon dioxide emission coefficient of energy industry \( j \); \( E_j \) is the carbon dioxide emission of energy industry \( j \). Based on Equation (7), the individual emission due to energy combustion of the 42 industries listed the input-output table, can be calculated. Using Equation (8), we can calculate the energy industry \( j \) derived carbon dioxide emission that is generated from industry \( k \). As shown in Equation (8), this can be simply achieved by multiplying the generated energy investment of the energy industry \( j \) that is used for industry \( k \) and coefficient (for industry \( j \)) computed using Equation (7). Thus, the total carbon dioxide emission of industry \( k \) includes the sum of the energy, and the segment used for industry \( k \), derived from each energy industry, which can be computed as:

\[ E^k = \sum_j E^k_j = \sum_j C^j_k \times e_j \]  

(7)

Based on the above calculation process, from Equations (3) to (8), we can calculate the individual emission of the 42 industries due to energy combustion.

2.2.2. Carbon dioxide emission from cement production. Multiple complex chemical reactions are involved in the cement production process, and most of them yield carbon dioxide as a side product. The equation for calculating carbon dioxide emission generated from cement production, a non-metallic mineral products industry is:

\[ EC = QC \times u \]  

(8)

where, \( EC \) is the carbon dioxide emission from cement production; \( QC \) is the total output of the cement production; \( u \) is the carbon dioxide emission coefficient for cement production. The coefficient used in this study is the coefficient for Portland cement, obtained from Greenhouse Gas Protocol, whose value is 0.5021016, which implies that the carbon dioxide emission yielded per ton of cement output tone is 0.5021016 tons.

3. Results and analysis

3.1. Design of scenarios

In this study, we investigated the impact of four influencing factors, namely, the transformational energy, energy invested in gross capital formation, energy exported or transferred, and the emission from the process of cement production. To separately investigate the impact of these factors, 16 scenarios were designed, and for each scenario, we calculated the total carbon emission and the emission from the intermediate and the final demand. The details of all scenarios are shown in Table 1.

| Scenario | If transformational energy is subtracted (1 is yes and 0 is no) | If energy invested in the gross capital formation is subtracted (1 is yes and 0 is no) | If energy is exported (1 is yes and 0 is no) | If CO2 from cement manufacture is added (1 is yes and 0 is no) |
|----------|---------------------------------------------------------------|--------------------------------------------------------------------------------|------------------------------------------|---------------------------------------------------------------|
| I        | 0                                                             | 0                                                                            | 0                                        | 0                                                             |
| II       | 0                                                             | 0                                                                            | 0                                        | 1                                                             |
When the variable takes the value 1, it means that the variable was considered, while 0 means that the variable was not considered. The results of a situation where all four variables were taken as 1 were used as the baseline scenario (Table 1).

3.2. Calculation of carbon emissions and analysis of the underlying factors
Using the scenario XVI as the baseline scenario as a comparison, the calculation results of the remaining 15 scenarios were obtained, and their deviations are shown in Table 2.

| Scenario | CO₂ from demand (10⁴t) | intermediate CO₂ (10⁴t) | CO₂ from final demand (10⁴t) | Total CO₂ (10⁴t) |
|----------|------------------------|-------------------------|-----------------------------|-----------------|
| Scenario I | -12.36%                | 44.91%                  | -10.23%                     |
| Scenario II | -1.73%                 | 44.91%                  | 0.00%                       |
| Scenario III | -11.54%                | 23.78%                  | -10.23%                     |
| Scenario IV | -0.92%                 | 23.78%                  | 0.00%                       |
| Scenario V | -11.30%                | 17.43%                  | -10.23%                     |
| Scenario VI | -0.67%                 | 17.43%                  | 0.00%                       |
| Scenario VII | -10.47%                | -4.17%                  | -10.23%                     |
| Scenario VIII | 0.16%                | -4.17%                  | 0.00%                       |
| Scenario IX | -12.98%                | 60.95%                  | -10.23%                     |
| Scenario X | -2.35%                 | 60.95%                  | 0.00%                       |
| Scenario XI | -12.01%                | 35.71%                  | -10.23%                     |
| Scenario XII | -1.38%                | 35.71%                  | 0.00%                       |
| Scenario XIII | -11.64%               | 26.35%                  | -10.23%                     |
| Scenario XIV | -1.02%                | 26.35%                  | 0.00%                       |
| Scenario XV | -10.63%                | 0.00%                   | -10.23%                     |

If the transformational energy is not considered, the carbon dioxide emission from intermediate demand get overestimated, and the carbon dioxide emission from the final demand get underestimated. As shown in Table 2, when the three segments were not subtracted and the emission from the process of cement production was added, the value of estimated carbon dioxide emission from intermediate demand was 0.16% higher than the baseline scenario and 4.17% lower than the final demand. This is not difficult to explain since if we do not subtract the transformational energy, the results reflect the situation where all energy inputs are used for combustion, but a large part of the inputs are used for
generating transformational energy. The problem arises when this part of the energy will be taken into calculation again (double calculation) when they are used for combustion after being converted into a new energy source. Consequently, when the carbon dioxide emission of one industry having an energy conversion process is calculated, the carbon dioxide emission from energy combustion is overestimated.

If the energy invested in gross capital formation is not subtracted, the carbon dioxide emission from middle demand would be underestimated, and the carbon dioxide emission from the final demand would be overestimated. As shown in Table 2, when the energy invested in the gross capital formation was not subtracted but assigned the value 1 for other three variables, the estimated carbon dioxide emission from middle demand was 1.38% lower in comparison with the baseline scenario. On the other hand, the carbon dioxide emission from final demand was 35.71% higher. The reason for these differences is that the energy invested in the gross capital formation was stored instead of being burnt; thus, the carbon dioxide emission from final demand was overestimated, while in the case where total emission was given, an underestimation of the actual carbon dioxide emission from the middle demand occurred.

If the energy exported or transferred is not subtracted, the carbon dioxide emission from the middle demand gets underestimated, and the carbon dioxide emission from the final demand gets overestimated. As shown in Table 2, when the energy exported or transferred was not subtracted but considered 1 for other three variables, the carbon dioxide emission from the middle demand was 1.02% lower in comparison with the baseline scenario, whereas the carbon dioxide emission was 35.71% higher than the baseline scenario from the final demand. In terms of the reason, the combustion of energy exported or transferred does not increase the local carbon dioxide emission, as it occurs outside of the local area.

For the the emission from the process of cement production, the estimated carbon dioxide emission (non-metallic mineral products industry) from the cement process was underestimated, and the estimated total emission was underestimated. Cement production-related CO₂ emission refers to the carbon dioxide emission obtained from the multiple complex chemical reactions involved in the cement production process, which offer a non-energy-burning carbon dioxide emission. By using the calculation methods described above, the estimated national cement production-related CO₂ emission in China (2012) was 1,096.614 million tons. As shown in Table 2, setting all variables to 1 had no impact on the emission from the final demand, but it caused a 10.63% of underestimation in the calculation results of the emission from the middle demand, and a 10.23% underestimation of the total emission.

4. Conclusion

In this study, we investigated the impact of four factors on the carbon dioxide emission calculations through an input-output analysis. Our observations included: first, we considered two main categories of carbon dioxide emissions: the energy combustion emission and cement process emission. This modified method did not only avoid the inconsistency of the data selection in the energy consumption method, the heavy multi-industry calculation workload in the life cycle evaluation method, and the inaccuracy in input-output method, but also offered at least two enormous advantages: it generated more accurate results, and it can be easily employed, with relatively fewer steps for multi-province and multi-industry analyses. Second, with regard to the calculation accuracy, all factors exhibited an impact. Notably, the “the emissions from the process of cement production” factor had a considerable influence on the calculation of the total carbon emission, while the other three factors mostly caused changes in the emission proportions. We conclude that the results were the most accurate when all the four factors were considered. If the transformational energy segment was not removed, the estimated carbon dioxide emission from intermediate demand was 0.16% higher than the baseline scenario, and was 4.17% lower than the baseline scenario from the final demand; if the energy invested in gross capital formation was not considered, the estimated carbon dioxide emission from intermediate demand was 1.38% higher than the baseline scenario, and 35.71% lower than the baseline scenario from the final demand. If the energy exported and transferred was not subtracted, the estimated carbon dioxide emission from intermediate demand was 1.02% higher than the baseline scenario, and 26.35%
lower than the baseline scenario from the final demand, and if the carbon emission from the cement production were not included, the estimated carbon dioxide emission from intermediate demand was 10.63% higher than the baseline scenario, and 10.23% lower than the baseline scenario from the final demand.

In the end, we propose four suggestions for better reduction in the carbon dioxide emission: first, we need to further optimize the energy consumption structure in China and try to reduce the proportion of coal (as well as other high-carbon energy sources) consumption and increase the proportion of clean energy, e.g., natural gas. Second, due to its fundamental importance in estimating the energy and environment related problems and carbon dioxide emission, the calculation method should draw more attention in the future, and thus more research needs to be done on the improving the accuracy of the calculation methods. Third, we also need to pay attention to the choice of the calculation method; the selected method should have a high accuracy within the error tolerance.

5. References
[1] Costa R C D. 2001 Do model structures affect findings? Two energy consumption and CO₂-emission scenarios for Brazil in 2010. Energy Policy. 10 29 777-85.
[2] Yao CS, Chen CY and Li M. 2012 Analysis of rural residential energy consumption and corresponding carbon emissions in China. Energy Policy. 4 41 445-450.
[3] Wu J, Zhu Q and Liang L. 2016 CO₂ emissions and energy intensity reduction allocation over provincial industrial sectors in China. Applied Energy. 166 282-291.
[4] Sumabat A K., et al. 2016 Decomposition analysis of philippines CO₂ emissions from fuel combustion and electricity generation. Applied Energy. 164 795-804.
[5] Xu P and Tao X. 2018 Decomposition of carbon intensity in electricity production: Technological innovation and structural adjustment in China’s power sector. Journal of Cleaner Production. 172 805-818.
[6] Liu Y, Langer V, Høgh-Jensen H and Egelyng H. 2010 Life cycle assessment of fossil energy use and greenhouse gas emissions in Chinese pear production. Journal of Cleaner Production. 14 18 1423-30.
[7] Zhao Z., et al. 2017 Life cycle assessment of primary energy demand and gas (GHG) emissions of four propylene production pathways in China. Journal of Cleaner Production. 1 163 285-92.
[8] Cao H, Li H, Cheng H, Luo Y, Yin R and Chen Y. 2012 A carbon efficiency approach for life-cycle carbon emission characteristics of machine tools. Journal of Cleaner Production. 4 37 19-28.
[9] Rajaeifar M A, Akram A, Ghabadian B, Rafiee S and Heidari M D. 2014 Energy-economic life cycle assessment (LCA) and greenhouse gas emissions analysis of olive oil production in Iran. Energy. 4 66 139-149.
[10] Peng C. 2016 Calculation of a building's life cycle carbon emissions based on Ecotect and building information modeling. Journal of Cleaner Production. 112 453-65.
[11] Yang X, Hu M, Wu J and Zhao B. 2018 Building-information-modeling enabled life cycle assessment, a case study on carbon footprint accounting for a residential building in China. Journal of Cleaner Production. 183 729-43.
[12] Zhu Q, Peng X and Wu K. 2012 Calculation and decomposition of indirect carbon emissions from residential consumption in China based on the input–output model. Energy Policy. 3 48 618-26.
[13] Wei J, Huang K, Yang S, Li Y, Hu T and Zhang Y. 2017 Driving forces analysis of energy-related carbon dioxide (CO₂) emissions in Beijing: An input–output structural decomposition analysis. Journal of Cleaner Production. 1 163 58-68.
[14] Zhang YJ, Bian XJ, Tan W and Song J. 2017 The indirect energy consumption and CO₂ emission caused by household consumption in china: an analysis based on the input–output method. Journal of Cleaner Production. 1 163 69-83.
[15] Lin BQ and Xie X. 2015 CO₂ emissions of China's food industry: An input–output approach. Journal of Cleaner Production. 112 1410-21.
[16] Su B, Ang B W and Li Y. 2017 Input-output and structural decomposition analysis of Singapore's carbon emissions. *Energy Policy*. 105 484-92.

[17] Long Y and Yoshida Y. 2018 Quantifying city-scale emission responsibility based on input-output analysis – insight from Tokyo, Japan. *Applied Energy*. 218 349-60.

[18] Pan W., et al. 2018 China’s inter-regional carbon emissions: an input-output analysis under considering national economic strategy. *Journal of Cleaner Production*. 197 794-803.