Correlation analysis of CO₂ emission in logistics and other industries of China

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Abstract. The paper calculates the total volume of CO₂ emission of the logistics industry in China, the consumption factor and distribution factor based on the statistical yearbook and the input-output table, and analyzes the correlation between CO₂ emission in the logistics industry and other industries of China. The result suggests that its total CO₂ emission volume shows a linear upward trend, but its average growth rate and emission intensity are going down year by year. As the CO₂ emission from the logistics industry is closely forward-correlated with that of the manufacturing, the construction industry and the logistics industry, it has a strong driving impact on the CO₂ emission of the industries concerned. Meanwhile, the backward-correlation with the manufacturing and the electric power, gas and water production and supply industries, and the logistics industry makes the logistics industry the greatest consumer of CO₂ emission from these industries. The development of the low CO₂ emission-oriented logistics industry requires a reduction of indirect CO₂ emission in the forward-correlated industries as well as the backward-correlated industries.

1. Introduction

Based on China Statistical Yearbook, the logistics industry of China (namely transport, storage and post, referred to as the logistics industry in the paper) shows a growing trend of energy consumption from 7.32% in 2005 to 9.41% in 2017 among all industries in China. However, the proportion of the logistics industry in GDP declined from 5.70% in 2005 to 4.53% in 2017, and accounted for only 4.50% in 2018. There is an increasingly widening gap between its energy consumption and output value. Lin B and Xie C (2014) proposed that the development of transport further pushes forward the growth of CO₂ emission in China, which is still growing all the way [1]. Chen Lei and Xu Linyu (2017) believed that the transport, storage and post industries feature net energy export[2]. As a bridge connecting the manufacturing industry and consumption behaviors, logistics has been undergoing rapid development with extending industrial chain and widening correlations with other industries. The increase of CO₂ emission from the logistics industry would have an impact on the correlated industries, which in turn, would further boost the CO₂ emission of the logistics industry. Studies on the correlation in terms of CO₂ emission mainly focus on agriculture[3], industry[4-5] and construction[6-7], with few researches on the correlation of CO₂ emission from the logistics industry and other industries. A research on the spreading characteristic of CO₂ emission of Beijing’s transport between the year 2007 and 2010 based on input-output by Cui Tiening and Hu Na (2014) proposed that the influence and sensitivity of the CO₂ emission from transport stays above the average[8]. Meanwhile, Tan Qiong and Tan Juan (2016) analyzed the correlation between CO₂ emission of Beijing’s transport between the year 1995 and 2010 with other industries and its impact, revealing a strong correlation between transport and the retail industry in terms of CO₂.
emission[9]. The paper, based on the input-output analysis, studies the correlation between the logistics industry and other industries in terms of CO₂ emission by time sequence to give references to the development of the logistics industry orienting toward low CO₂ emission.

2. Analysis of the total CO₂ emission and intensity in the logistics industry and their fluctuations

2.1. Sources of data

The paper studies the correlation of the logistics industry with other fields in terms of CO₂ emission, with data from the China input-output table and China Energy Statistical Yearbook. Researches have different approaches[10-13] for the categorization of industries. This paper involves 9 industries based on their functions and China Energy Statistical Yearbook, including: (1) agriculture, forestry, animal husbandry and fishery; (2) mining and quarrying; (3) manufacturing; (4) electric power, gas and water production and supply; (5) construction; (6) logistics; (7) wholesale, retail trade and hotel, restaurants; (8) other industries; (9) residential consumption (the industrial sectors are replaced by serial numbers in the table).

2.2. Calculation of the total value and intensity of CO₂ emission from energies consumed in different industries

The CO₂ emission from energy consumption in different industries is calculated by the level of energy consumption times the corresponding CO₂ emission factor[8]. Based on previous research results, the calculation of CO₂ emissions from various industries in China can be obtained as follows[14]:

\[ DC = \sum E_{i1} \cdot F_{i1} \cdot C_{i1} + \sum E_{j2} \cdot C_{j2} \]  (1)

In which, \( DC \): CO₂ emissions from various industries;
\( E_{i1}, E_{j2} \): primary and secondary energy consumption;
\( F_{i1}, C_{i1} \): conversion factor from physical units to coal equivalent of the \( i \)-th primary energy;
\( F_{j2}, C_{j2} \): CO₂ emission factor of primary and secondary energy.

CO₂ emission intensity refers to the amount of CO₂ emission from energies consumed by a certain industry per unit of output[6], expressed as:

\[ C_i = \frac{DC_i}{X_i} \]  (2)

In which, \( DC_i \): the CO₂ emission from the \( i \)-th department;
\( X_i \): the total output value of the \( i \)-th department.

Primary energies consumed by the logistics industry in China and the relevant factors are shown in the table 1:

### Table 1. Conversion factors \( F_i \) from physical units to coal equivalent and the CO₂ emission factors \( C_i \).

| Serial number | Energy   | \( F_i \) (kgce/kg) | \( C_i \) (t CO₂/t Standard coal) |
|---------------|----------|----------------------|----------------------------------|
| 1             | Coal     | 0.7143               | 0.7559                           |
| 2             | Coke     | 0.9714               | 0.855                            |
| 3             | Crude Oil| 1.4286               | 0.5857                           |
| 4             | Gasoline | 1.4714               | 0.5538                           |
| 5             | Kerosene | 1.4714               | 0.5714                           |
| 6             | Diesel   | 1.4571               | 0.5921                           |
| 7             | Fuel oil | 1.4286               | 0.6155                           |
| 8             | Natural gas | 1.33 kgce/m³ | 0.4483                           |
| 9             | Electricity | -                 | 0.6808 t CO₂/10⁶kWh            |

Among them, electricity power is a secondary energy, whose CO₂ emission factor is calculated based on the mean CO₂ emission factor of regional power grid as stipulated by NDRC in 2012. \( F_i \) of other
primary energies is from *China Energy Statistical Yearbook* and $C_i$ from 2006 *IPCC Guidelines for National Greenhouse Gas Inventory*.

2.3. *Changes in the CO$_2$ emission of the logistics industry of China*

The total CO$_2$ emission volume of primary energies consumed by industries in China between 2005 and 2017 is shown in figure 1, where the mining and quarrying industry is presenting a downward trend between 2015 and 2017 while the other 8 industries are on the rise. Although the total CO$_2$ emission volume of the logistics industry takes on a linear upward trend, its annual growth rates have been on a decrease since 2012. Recent efforts to promote clean energies among regions and industries coupled with major ecological projects aiming at emission reduction have been paying off.

![Figure 1](image1.png)

*Figure 1. The total CO$_2$ emission volume of primary energies consumed by nine industries in China from 2005 to 2017.*

From 2005 to 2015, the CO$_2$ emission intensity of various industries (figure 2) showed an overall trend of declining year by year. Especially, the electric power, gas and water production and supply industries made great progress in the reduction of CO$_2$ emission owing to the large base of CO$_2$ emission intensity. However, CO$_2$ emission intensity continued to fall in 2017 only in the mining and logistics sectors, while other industries picked up a growing trend. In 2017, the CO$_2$ emission intensity of the logistics industry dropped by 43.59% compared with 2005, ranking in the middle of the nine industries.

![Figure 2](image2.png)

*Figure 2. The intensity of CO$_2$ emission from nine industries in China from 2005 to 2017.*
3. Industrial correlation of CO2 emission in the logistics industry

3.1. Intensity matrix of industrial CO2 emission
To facilitate calculation, the intensity of industrial CO2 emission is represented by a diagonal matrix:

\[ C_{ij} = \begin{cases} 0, & i \neq j \\ C_i, & i = j \end{cases} \]  

(3)

3.2. Analysis on the factor variation of CO2 emission consumption of the logistics industry
(1) Direct consumption factor of CO2 emission
Direct consumption factor matrix:

\[ A = (a_{ij})_{n \times n} = \left( \frac{x_{ij}}{X_i} \right)_{n \times n}, (i, j = 1, 2, 3, \ldots, n) \]  

(4)

In which, \( x_{ij} \): the direct consumption of \( j \) department to \( i \) department;
\( X_i \): total input of \( j \) department.

The direct consumption factor of CO2 emission refers to the CO2 emission generated by direct consumption of products or services of other industries per unit of output[9]. The calculation matrix is:

\[ C_A = C_j A \]  

(5)

(2) Complete consumption factor of CO2 emission
The calculation matrix is:

\[ C_w = C_j [(I - A)^{-1} - I] \]  

(6)

In which, \( I \): identity matrix;
\( L = (I - A)^{-1} = (b_{ij})_{n \times n} \): Leontief inverse matrix.

The consumption factor of CO2 emission of the logistics industry represents the CO2 emission generated from the consumption of products or services of other industries per unit of output by the logistics industry[8], reflecting the dependence of the logistics industry on the other industries providing products or services to the logistics industry in terms of CO2 emission in a backward correlation.

Table 2. The consumption factor of CO2 emission of the logistics industry to nine industries in China from 2005 to 2017.

| Year | 2005 | 2007 | 2010 | 2012 | 2015 | 2017 |
|------|------|------|------|------|------|------|
| Industr ies | \( C_A \) | \( C_w \) | \( C_A \) | \( C_w \) | \( C_A \) | \( C_w \) | \( C_A \) | \( C_w \) | \( C_A \) | \( C_w \) |
| (1) | 0.026 | 0.172 | 0.019 | 0.139 | 0.030 | 0.143 | 0.013 | 0.091 | 0.008 | 0.081 | 0.000 | 0.051 |
| (2) | 0.081 | 0.990 | 0.036 | 0.732 | 0.028 | 0.697 | 0.006 | 0.639 | 0.004 | 0.451 | 0.001 | 0.316 |
| (3) | 1.971 | 6.373 | 1.629 | 5.235 | 1.421 | 4.760 | 1.117 | 3.938 | 0.923 | 3.555 | 0.790 | 2.560 |
| (4) | 0.705 | 3.220 | 0.410 | 2.771 | 0.353 | 2.417 | 0.572 | 2.405 | 0.534 | 2.129 | 0.631 | 1.786 |
| (5) | 0.007 | 0.013 | 0.002 | 0.003 | 0.002 | 0.004 | 0.003 | 0.002 | 0.002 | 0.005 | 0.000 | 0.001 |
| (6) | 0.621 | 0.982 | 0.323 | 0.538 | 0.320 | 0.548 | 0.500 | 0.753 | 0.499 | 0.759 | 0.300 | 0.458 |
| (7) | 0.052 | 0.171 | 0.043 | 0.119 | 0.048 | 0.133 | 0.048 | 0.137 | 0.053 | 0.149 | 0.052 | 0.129 |
| (8) | 0.135 | 0.336 | 0.175 | 0.347 | 0.155 | 0.329 | 0.153 | 0.347 | 0.145 | 0.353 | 0.169 | 0.337 |
| (9) | 0.040 | 0.115 | 0.037 | 0.091 | 0.025 | 0.067 | 0.019 | 0.055 | 0.025 | 0.075 | 0.012 | 0.035 |

Since 2005, the energy consumption factor of the logistics industry to other industries has been in the middle among the nine industries. From the CO2 emission consumption factor of the logistics industry in table 2, it is known that: (1) The complete consumption factor of CO2 emission of the logistics industry is far higher than the direct consumption factor, indicating the strong pulling effect of the logistics industry on the indirect CO2 emission of the backward-related industries. (2) The CO2 emission from the logistics industry to the manufacturing and the electric power, gas and water production and supply industries as well as the direct and indirect consumption factors of the logistics industry have always been in top 2, indicating that the logistics industry consumes the most CO2 emissions from the three industries. The consumption of CO2 emission from the logistics industry to the construction industry has been at a low level, indicating a weak backward-correlation between the logistics industry and the construction industry in terms of CO2 emission. (3) The direct consumption factor of CO2
emission from the logistics industry to the mining and quarrying industry gradually dropped from the 5th place to the 7th or 8th place among the 9 industries, while the complete consumption factor dropped only from the 3rd place to the 4th or 5th place, indicating that the direct backward-correlation between the logistics industry and mining and quarrying industry in terms of CO₂ emission was weakening despite the fact that the indirect backward-correlation between the two remained strong. The direct consumption factor of CO₂ emission of the logistics industry to other industries seldom fluctuates while there has been changes in the complete consumption factor. Therefore, it is necessary to attach importance to the indirect CO₂ emission consumption of the logistics industry to the mining and quarrying industry and other industries.

3.3. Analysis on the changes of CO₂ emission distribution factor in the logistics industry

(1) Direct distribution factor of CO₂ emissions

The direct distribution factor of CO₂ emissions represents the amount of CO₂ emissions generated by a certain industry per output value that are directly distributed to other industries [9]. The calculation matrix is:

\[ C_H = C_{ij}H = C_{ij}(h_{ij})_{n \times n} = C_{ij} \left( \frac{x_{ij}}{X_i} \right)_{n \times n}, (i, j = 1, 2, 3, \ldots, n) \]  

(7)

In which, \( X_i \): the total output of department \( i \).

(2) Complete distribution factor of CO₂ emissions

The complete distribution factor of CO₂ emission represents the amount of CO₂ emission generated per unit output value by some certain industry and allocated to the forward-correlated industries directly or indirectly[9], reflecting how far this industry has promoted the complete CO₂ emission to the other industries. The calculation matrix is:

\[ C_v = C_{ij}[(I - H)^{-1} - I] \]  

(8)

Table 3. The distribution factor of CO₂ emission of the logistics industry in China from 2005 to 2017.

| Year | Industries | 2005 | 2007 | 2010 | 2012 | 2015 | 2017 |
|------|------------|------|------|------|------|------|------|
| (1)  |            | 0.169| 0.479| 0.114| 0.325| 0.099| 0.286|
| (2)  |            | 0.168| 0.403| 0.174| 0.359| 0.154| 0.351|
| (3)  |            | 1.769| 6.499| 1.440| 5.721| 1.296| 5.301|
| (4)  |            | 0.142| 0.431| 0.057| 0.314| 0.044| 0.278|
| (5)  |            | 0.372| 1.073| 0.676| 1.297| 0.711| 1.320|
| (6)  |            | 0.621| 0.982| 0.323| 0.538| 0.320| 0.548|
| (7)  |            | 0.186| 0.541| 0.402| 0.638| 0.237| 0.422|
| (8)  |            | 0.305| 0.882| 0.229| 0.564| 0.294| 0.682|
| (9)  |            | 0.192| 0.571| 0.170| 0.442| 0.143| 0.340|

Table 3 shows that: (1) The complete distribution factor of CO₂ emissions in the logistics industry to the forward-correlated industries is greater than the direct distribution factor, indicating that the logistics industry has a relatively strong ability to promote the indirect CO₂ emissions of the forward-correlated industries, whose indirect demands for the logistics industry lead to a great deal of CO₂ emission from the logistics industry. (2) The manufacturing industry has the highest correlation both forward and backward in terms of CO₂ emissions from the logistics industry. The construction industry, the weakest in terms of backward correlation, ranks the 2nd or 3rd in the forward correlation. The forward correlation within the logistics industry is close as well. This indicates that the logistics industry has greatly promoted the complete CO₂ emissions from manufacturing, construction and logistics. The electric power, gas and water production and supply industries, ranking second in the backward correlation, are weakly correlated in the forward correlation, indicating the effect of the logistics industry on it is relatively weak. (3) The logistics industry takes on a year-on-year downward trend of CO₂ distribution factor for most industries, indicating that the recent efforts of energy conservation and emission
reduction by the logistics industry is paying off. However, despite a decline of CO₂ distribution factor in the wholesale, retail trade and hotel, restaurants industries before 2015, there has been a rising trend later. For farming, forestry, animal husbandry and fishery industries, the direct distribution factor of CO₂ emissions in 2017 began to grow again. This indicates that there has been an increasing trend in the promotion of complete CO₂ emission of the logistics industry to these two industries.

4. Conclusion

Through the input-output analysis, the paper studied the correlation between the logistics industry and other industries in China in terms of CO₂ emission based on time sequencing between 2005 and 2017, which found that:

- Although the total CO₂ emission of the logistics industry in China is on the rise, the average growth rate has been declining year by year since 2012. The CO₂ emission intensity of the logistics industry is declining year by year, 43.59% lower in 2017 than in 2015. Clearly, efforts including the CO₂ trading pilot launched in 2013 and the upgrading of the logistics industry in 2015 have been paying off, with vigorous efforts in developing environment-friendly logistics and energy conservation.

- The close forward-correlation between the logistics industry, manufacturing and construction as well as within the logistics industry in terms of CO₂ emission is promoting the CO₂ emission from these industries. The demand of these industries for logistics leads to the growth of CO₂ emission from the logistics industry. The logistics industry has a weak impact on the electric power, gas and water production and supply, wholesale, retail trade and hotel, restaurants, and agriculture, forestry, animal husbandry and fishery.

- The logistics industry is closely backward-correlated with the manufacturing, electric power, gas and water production and supply industries, highly dependent on these industries and consumes the most CO₂ emissions. The backward correlation between the logistics industry and the construction industry in terms of CO₂ emission is the weakest, indicating that the CO₂ emission of the logistics industry is not strongly dependent on the construction industry. In addition, the indirect CO₂ emission from the logistics industry to the mining and quarrying and other industries tends to fluctuate.

Featuring huge energy consumption and CO₂ emissions, the logistics industry of China needs to work on reducing CO₂ emission not only by phasing out inefficient outdated equipment, but also by utilizing cars and ships of fuel efficiency, adjusting the structure of logistics capacity, promoting the use of container trailer LNG, as well as standard and specialized ships on a large scale. Aiming at smart logistics, it needs to reform the energy consumption for energy conservation and emissions reduction. In addition, it needs to reduce the indirect CO₂ emissions to the forward-correlated industries while paying attention to the backward-correlated industries in terms of CO₂ emission, including the manufacturing and the production and supply industries of electric power, gas and water. Finally, there is the need to strengthen government incentives, guidance, supervision and inspection mechanism to promote the logistics industry and other industries toward long-term development of low CO₂ emissions.

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