Analysis of factors affecting carbon emissions in Tianjin

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Abstract. According to the IPCC carbon emission calculation method, Tianjin's carbon emissions were calculated from 2000 to 2017, and the main factors affecting carbon emissions were analyzed and studied using the LMDI model system. The results show that Tianjin’s energy consumption carbon emissions continued to increase from 2000 to 2017, and have declined significantly in recent years. Among the carbon emissions of energy consumption, coal produced the most carbon emissions, followed by crude oil and coke; Among the factors that affect Tianjin’s carbon emissions from 1997 to 2017, economic development has the largest positive effect, and energy consumption intensity has the largest negative effect; Tianjin’s energy consumption is unreasonable, and it mainly depends on coal, crude oil and other energy sources.

1. Introduction
Since the reform and opening up, after 40 years of spectacular growth, China ’s GDP has grown at an average annual rate of 10%, making it the world ’s second largest economy, and its carbon emissions are also increasing. In the "Paris Climate Agreement", our government promised to reach the peak of carbon emissions around 2030, and the carbon emissions per unit of GDP decreased by 60% -65% compared with 2005. In order to achieve the goal, it is necessary to study the changes in carbon emissions from a regional perspective and provide a basis for formulating a reasonable carbon emission policy.

Tianjin is an important port city in China. It is also the birthplace of modern Chinese industry and an important industrial city. It is also a city with developed industries as the center. These industrial enterprises are the main force of Tianjin's economy and an important part of Tianjin's total energy consumption. Tianjin is also the first batch of pilot cities for low-carbon cities. From the perspective of the existing energy and economic structure, it is very necessary for Tianjin to achieve the goal of energy conservation and emission reduction and achieve sustainable development without reducing economic growth. This article analyzes the influencing factors of Tianjin's carbon emission reduction, and provides the necessary basis for Tianjin to formulate a scientific carbon emission reduction policy.

Domestic and foreign scholars' research on carbon emissions is mainly concentrated in three aspects:
(1) Research on influencing factors of carbon emissions. In view of China's current stage of economic growth and energy consumption characteristics, Liu Xiying appropriately modified the Kaya identities, introduced urbanization factors, and studied the influencing factors of carbon emissions at this stage [1]. Shen Xiaoyan used gray correlation analysis to discuss China's carbon emissions and its relationship with various influencing factors, and concluded that population growth contributed the most to carbon emissions, The rational choice of energy consumption structure in economic activities is far more important than the impact of economic growth on carbon emissions [2]. (2) Research by region. Sun
Xiumei and others analyzed the research characteristics of carbon emissions in Shandong Province, and conducted empirical research on the influencing factors of carbon emissions based on the Kaya formula [3]. Tian Yun and others calculated the carbon emissions of Wuhan from 1996 to 2009 based on 14 main aspects of carbon sources, and further decomposed the carbon emission influencing factors based on the LMDI model [4]. (3) Research on various analysis methods. Ding Weijia and others used the ridge estimation method and the STIRPAT model to quantitatively analyze the impact of population, wealth, and technological factors on China's manufacturing carbon emissions, and constructed a STIRPAT model that introduced the quadratic term of population and wealth [5]. Liu Yuan and others applied the Logarithmic Average Weighted Decomposition Method (LMDI) to factorize the carbon emission intensity indicators based on the terminal consumption data of each department in Xiamen from 2005 to 2010, and extended the traditional analysis to focus only on the energy carbon emissions of the industrial sector to Comprehensively consider the impact of energy and non-energy activities consumed by industrial sectors and households [6].

At present, research on the influencing factors of Tianjin's carbon emissions is relatively rare. This paper calculates and analyzes Tianjin's total carbon emissions, total energy consumption, and per capita carbon emissions from 2000 to 2017. An LMDI decomposition model was established to analyze the impact and contribution rate of each factor, with a view to providing a basis for Tianjin to formulate a scientific carbon emission reduction policy.

2. Research methods and data sources

2.1. Calculation method of carbon emissions

At present, there is no data published by the authority on carbon emissions in Tianjin. Therefore, based on the research results of the IPCC, energy consumption is used to calculate [7]:

\[ C = \sum_{i=1}^{n} E_i f_i \]  

(1)

In the formula, C is the carbon emissions; \( E_i \) is the energy consumption, based on standard coal; \( f_i \) is the energy carbon emission coefficient; i is the energy type. The carbon emission coefficients of various carbon sources are shown in Table 1.

| Carbon source | Carbon emission factor | Carbon source | Carbon emission factor | Carbon source | Carbon emission factor |
|---------------|------------------------|---------------|------------------------|---------------|------------------------|
| coal          | 0.7559                 | Fuel oil      | 0.6185                 | Diesel        | 0.5921                 |
| Coke          | 0.8550                 | gasoline      | 0.5538                 | natural gas   | 0.4483                 |
| crude         | 0.5857                 | kerosene      | 0.5714                 | electric power| 2.5255                 |

2.2. Decomposition method of carbon emission influencing factors

This article uses the Dexter's Index Decomposition Method (LMDI) to analyze the carbon emission factors affecting Tianjin. The LMDI method satisfies the factor reversibility, can eliminate the residual term, and overcomes the shortcomings of the residual term or improper decomposition of the residual term after being decomposed by other methods, making the model more convincing [8]. According to this method, the relationship between Tianjin's total carbon emissions and various influencing factors is expressed as:

\[ C = \text{POP} \times \left( \frac{\text{GDP}}{\text{POP}} \right) \times \left( \frac{\text{PE}}{\text{GDP}} \right) \times \left( \frac{\text{C}}{\text{PE}} \right) \]  

(2)

In the formula, C is the total carbon emissions, \( \text{POP} \) is the total population, GDP is the regional gross domestic product, and PE is the total energy consumption. Let \( P = \text{POP} \) be the population size, \( A = \text{GDP} \)
/ POP be the level of economic development, B = PE / GDP be the intensity of energy consumption, and D = C / PE be the energy consumption structure. Let the carbon emissions change value from year 0 to t be \( \Delta C \), the total population change be \( \Delta P \), the level of economic development change \( \Delta A \), the energy consumption intensity change \( \Delta B \), and the energy consumption structure \( \Delta D \). The addition factorization using the LMDI method yields the following formula:

\[
\Delta C = C_t - C_0 = \Delta P + \Delta A + \Delta B + \Delta D
\]

Population size effect:
\[
\Delta P = \left( \frac{C_t - C_0}{\ln C_t - \ln C_0} \right) \left( \ln \frac{P_t}{P_0} \right)
\]

Economic development effect:
\[
\Delta A = \left( \frac{C_t - C_0}{\ln C_t - \ln C_0} \right) \left( \ln \frac{A_t}{A_0} \right)
\]

Energy consumption intensity effect:
\[
\Delta B = \left( \frac{C_t - C_0}{\ln C_t - \ln C_0} \right) \left( \ln \frac{B_t}{B_0} \right)
\]

Structural effects of energy consumption:
\[
\Delta D = \left( \frac{C_t - C_0}{\ln C_t - \ln C_0} \right) \left( \ln \frac{D_t}{D_0} \right)
\]

In the formula, \( r_n \) is the contribution rate of an influencing factor; \( \Delta N \) is \( \Delta P, \Delta A, \Delta B, \Delta D \), which represents the contribution of an influencing factor to the change in carbon emissions based on LMDI decomposition.

2.3. Data Sources
The data in this article comes from Tianjin Statistical Yearbook 2001-2018. The coefficients for the conversion of various types of energy into standard coal are from the General Rules for Calculation of Comprehensive Energy Consumption (GB / T 2589-2008). The carbon emission coefficients for various types of energy are mainly derived from the default values of the IPCC National Greenhouse Gas Emission Inventory Guidelines. For other coefficients, see Wang Haizhen[9] CO₂ emission coefficient conversion in other studies.

3. Overall analysis of Tianjin's carbon emissions

3.1. Total analysis
It can be obtained from the calculation of Tianjin's energy consumption carbon emissions from 2000 to 2017. From 2000 to 2017, Tianjin's total carbon emissions and per capita carbon emissions showed a trend of decline after growth (see Figure 1). The total carbon emissions increased from 3,253,700 tons in 2000 to 66,589,900 tons in 2013, indicating that with the rapid development of industrialization and urbanization and the improvement of people's living standards, the energy consumption of construction and living continued to increase, leading to Per capita carbon emissions are increasing. The total carbon emissions have decreased from 63.508 million tons in 2014 to 54.369 million tons in 2017. The trend of changes in per capita carbon emissions has also been basically similar, and the total energy consumption has also shown a downward trend since 2023, while GDP has been maintained at a high speed. The growth and good economic situation indicate that the Tianjin Municipal Government has adopted adjustment measures for high energy-consuming industries in recent years, and the total energy consumption has decreased, which has led to a significant reduction in total carbon emissions.
Figure 1. Relationship between Tianjin's economic growth, energy consumption, and carbon emissions from 2000 to 2017

3.2. Carbon emission analysis of energy consumption
From 2000 to 2017, Tianjin's 9 major energy consumption and carbon emissions are shown in Figures 2 and 3. It can be seen that the annual energy consumption and carbon emissions of Tianjin are similar. The top energy sources are coal and crude oil in that order. And coke, and power consumption has been increasing in recent years. Each year, coal consumption causes the most carbon emissions, and natural gas causes the least carbon emissions. Coal carbon emissions have shown a growth trend in the early stage, from 18.7298 million tons in 2000 to 40.485 million tons in 2012, which has begun to decline from 2013. The carbon emissions of coal in 2017 were 29.29757 million tons, which is close to the data of 2008 It shows that Tianjin's energy consumption is mainly coal, but the current coal consumption has fallen from 66% in 2002 to about 50%. Tianjin's second largest energy source that produces the most carbon emissions is crude oil. Although the growth trend of crude oil has always been below coal, carbon emissions have increased from 41.587 million tons in 2000 to 10.303 million tons in 2013. Decreased slightly, but remained around 9 million tons. It can be seen that Tianjin has for a long time been dominated by a high consumption and high emission extensive energy consumption model. This development model will inevitably lead to a continuous increase in carbon emissions. Although the consumption of electricity and energy has increased significantly in recent years, However, it does not belong to the main energy consumption. Therefore, the coal-based energy consumption structure is the main constraint on Tianjin's transition to a low-carbon development model. In the future, energy conservation and emission reduction will show a slight good trend but will remain severe.
4. Analysis of factors affecting carbon emissions in Tianjin

Using the LMDI-based full decomposition model to factorize carbon emissions from energy consumption in Tianjin from 2000 to 2017, the decomposition results and contribution rates of population size, economic development, energy intensity, and energy structure are obtained, as shown in Table 2 and Figure 4.

According to Table 2, from 2000 to 2017, the total carbon emissions of energy consumption in Tianjin increased by 21,835,200 tons. Among them, the economic development effect is the main driving force for carbon emissions growth, and the reduction in energy consumption intensity is the main factor for carbon emissions reduction. From year to year, the influence and contribution of various factors on the amount of change in carbon emissions are different.
4.1. Population Size
The population size effect has a positive effect on the growth of carbon emissions, but the value is small. From Table 2, it can be seen that the proportion of population size effect in the increase of carbon emissions is low. From Figure 4, the contribution rate of population size is also small. In 2012, the size of the population contributed the most to carbon emissions, but since then, population factors have had a smaller or even negative impact on carbon emissions, indicating that increasing population has a smaller role in driving carbon emissions.

Table 2. Decomposition results of factors affecting carbon emissions in Tianjin

| years      | Population size effect | economic development effect | Energy consumption intensity effect | Energy consumption structure effect | Carbon emissions increase |
|------------|------------------------|-----------------------------|------------------------------------|------------------------------------|--------------------------|
| 2000-2001  | 8.93                   | 359.53                      | -243.47                            | -489.61                            | -364.61                  |
| 2001-2002  | 9.27                   | 331.23                      | -233.98                            | 93.22                              | 199.73                   |
| 2002-2003  | 13.20                  | 572.66                      | -385.26                            | 92.91                              | 293.51                   |
| 2003-2004  | 43.85                  | 669.00                      | -199.39                            | -53.76                             | 459.71                   |
| 2004-2005  | 74.52                  | 835.91                      | -496.50                            | -126.74                            | 287.19                   |
| 2005-2006  | 128.33                 | 445.32                      | -167.87                            | -168.37                            | 237.40                   |
| 2006-2007  | 161.75                 | 559.08                      | -462.72                            | -135.60                            | 122.51                   |
| 2007-2008  | 243.89                 | 885.46                      | -618.82                            | -329.57                            | 180.95                   |
| 2008-2009  | 209.36                 | 334.87                      | -105.60                            | -125.14                            | 313.53                   |
| 2009-2010  | 304.15                 | 798.83                      | -297.90                            | 55.53                              | 860.61                   |
| 2010-2011  | 254.78                 | 994.28                      | -586.53                            | -114.72                            | 547.81                   |
| 2011-2012  | 272.41                 | 581.07                      | -356.88                            | -408.98                            | 87.63                    |
| 2012-2013  | 267.87                 | 474.57                      | -1007.74                           | 391.75                             | 126.45                   |
| 2013-2014  | 193.32                 | 358.94                      | -339.47                            | -467.80                            | -255.01                  |
| 2014-2015  | 121.60                 | 191.68                      | -226.58                            | -425.04                            | -338.34                  |
| 2015-2016  | 56.94                  | 294.71                      | -362.58                            | -340.08                            | -351.01                  |
| 2016-2017  | -18.68                 | 235.63                      | -376.46                            | -65.03                             | -224.54                  |
| 2000-2017  | 1877.51                | 8279.69                     | -5687.13                           | -2286.55                           | 2183.52                  |

Figure 4. Contribution rate of influencing factors of carbon emissions in Tianjin
4.2. Economic development
The impact of economic development effects on carbon emissions has always dominated. From the perspective of year-to-year effects, the economic effects are positive in each year, which indicates that economic growth has a continuous driving effect on the growth of carbon emissions in Tianjin, especially the largest contribution rate of economic development in 2011-2012, indicating that economic growth during the study period was the decisive factor for the growth of energy consumption carbon emissions. It shows that while economic growth brings about the development of social material civilization, it also consumes a lot of energy and emits a lot of carbon dioxide.

4.3. Energy Consumption Intensity
Judging from the decomposition results and contribution rate, the intensity of energy consumption has a large negative effect on the increase of carbon emissions, and is the key factor that promotes the reduction of carbon emissions. From 2012 to 2013, its negative effect was the strongest, exceeding the positive effect caused by the economic development effect. In terms of contribution, the absolute value of the contribution of the energy consumption intensity effect is relatively high, which has a strong impact on changes in carbon emissions.

4.4. Energy Consumption Structure
The positive and negative effects of the energy consumption structure on the increase in carbon emissions change significantly, but in general, they show a smaller negative effect. The negative effect of energy consumption structure from 2011 to 2012 was the largest, exceeding the negative effect of energy consumption intensity on the increase of carbon emissions. From the perspective of contribution, the absolute value of the contribution rate of the energy consumption structure is only higher than the contribution rate of the population size, and the effect on carbon emissions and energy consumption intensity is relatively small. It shows that Tianjin's energy consumption structure is not reasonable, and high-carbon energy is the main source, especially coal.

5. Conclusion
The following conclusions are drawn from the analysis of Tianjin’s energy consumption carbon emissions and its influencing factors: (1) Tianjin’s energy consumption carbon emissions first increased and then declined. Among the nine energy sources, coal is the energy source with the highest carbon emissions. Natural gas has the lowest carbon emissions. (2) Economic development is a major factor in increasing carbon emissions, and the negative effects of energy consumption intensity have largely suppressed the increase in carbon emissions. (3) Tianjin's energy consumption structure is unreasonable, mainly coal, and the consumption structure needs to be optimized. In the future, Tianjin should focus on the adjustment of energy consumption structure, accelerate the transformation of economic development mode, and vigorously promote low-carbon development. At the same time as relevant departments make countermeasures, they should also promote energy-saving and low-carbon living in the entire people.

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