Research on the factors affecting carbon emission of energy consumption in the Beijing-Tianjin-Hebei region

Y S Huang, Y Q Yang, M S Shi

Department of Economics and Management, North China Electric Power University, Hebei, 071003, China

Email: 15176261181@163.com

Abstract. Quantitative analysis of the factors affecting carbon emissions has important guiding significance for reducing regional carbon emissions in the region. Therefore, this paper first systematically analyzes the changes in the total carbon emissions of energy consumption in the Beijing-Tianjin-Hebei region. Then, the improved STIRPAT model is used to analyze the influencing factors of carbon emissions from energy consumption. Finally, the co-integration test and error correction model are used to study the long-term equilibrium relationship and short-term changes of carbon emission and its influencing factors (economic level, population size, technological level and energy structure) in the Beijing-Tianjin-Hebei region.

1. Introduction

The emission of greenhouse gases such as CO₂ has brought about a negative impact on the development of human society. Reducing carbon emissions will be a protracted war in the process of China's economic development. As long as the status of coal-based energy utilization has not been fundamentally changed, China's fossil energy will inevitably have greater demand and put more pressure on the environment [1]. As one of China's new development business circles, the Beijing-Tianjin-Hebei region plays an important role in China's development, but it also faces serious problems of excessive energy consumption and excessive carbon emissions. Therefore, it is of great significance to study the influencing factors of carbon emissions from energy consumption in the Beijing-Tianjin-Hebei region.

At present, many scholars have conducted many in-depth studies on the factors affecting carbon emissions. Shuai, et al. combined the STIRPAT model with the use of the panel and time-series data to analyze the impacts of population, affluence and technology on the carbon emission of 125 countries at different income levels over the period of 1990-2011 [2]. Fernándezamador, et al. used the ARDL boundary test to study the cointegration relationship between Pakistan's carbon emissions, energy consumption, trade openness and financial development [3]. Al-Mulali, et al. used the STIRPAT model to analyze the relationship between carbon emissions, urbanization levels and energy consumption in MENA [4]. Chikaraishi proposed an alternative concept and analytical framework using the improved STIRPAT model to determine at what level of urbanization can cause less carbon dioxide in human activities [5]. Lv, et al. used the STIRPAT model to study the effects of specific sectors in the industrial system on environmental pollution through ridge regression [6].

However, these studies are mainly concentrated on the analysis of the national level. There are few studies on the influencing factors of carbon emissions at the provincial level. So, this paper establishes an extended STIRPAT model to quantitatively analyze the influencing factors of energy consumption.
carbon emissions in the Beijing-Tianjin-Hebei region. It is expected that these recommendations can provide reference for energy conservation and emission reduction in the region.

2. Analysis of carbon emissions in the Beijing-Tianjin-Hebei region

2.1. Calculation of carbon emissions

This paper calculates the calculation according to the algorithm published in the 2006 IPCC guidelines. The specific accounting methods are as follows:

\[ CE = \sum E_i \times NCV_i \times CEC_i \times COF_i \times \frac{44}{12} \]  

(1)

Where \( CE \) is the total amount of emissions, \( E_i \) is the amount of energy consumed, \( NCV_i \) is the low calorific value of energy, \( CEC_i \) is the carbon content per unit of calorific value of energy, and \( COF_i \) is the carbon oxidation rate.

Considering the availability of data, only eight types of energy are considered in this paper. The related indicators of various energy sources are shown in table 1.

| Energy     | Average low caloric value | Folded coal coefficient | Unit calorific value carbon content(ton/TJ) | Carbon oxidation rate | Carbon dioxide emission coefficient |
|------------|----------------------------|-------------------------|--------------------------------------------|----------------------|-----------------------------------|
| Raw coal   | 20908kJ/kg                | 0.7143kgce/kg           | 26.37                                      | 0.94                 | 1.9003kg-co/kg                     |
| Coke       | 28435kJ/kg                | 0.9714kgce/kg           | 29.5                                       | 0.93                 | 2.8604kg-co/kg                     |
| Crude oil  | 41816kJ/kg                | 1.4286kgce/kg           | 20.1                                       | 0.98                 | 3.0202kg-co/kg                     |
| Gasoline   | 43070kJ/kg                | 1.4714kgce/kg           | 18.9                                       | 0.98                 | 2.8179kg-co/kg                     |
| Kerosene   | 43070kJ/kg                | 1.4714kgce/kg           | 19.5                                       | 0.98                 | 3.0179kg-co/kg                     |
| Diesel     | 42652kJ/kg                | 1.4571kgce/kg           | 20.2                                       | 0.98                 | 3.0959kg-co/kg                     |
| Fuel oil   | 41816kJ/kg                | 1.4286kgce/kg           | 21.1                                       | 0.98                 | 3.1705kg-co/kg                     |
| Natural gas| 38931kJ/m³                | 1.3300kgce/m³           | 15.3                                       | 0.99                 | 2.1622kg-co/m³                     |

2.2. Analysis of carbon emissions in the Beijing-Tianjin-Hebei region

According to the calculation method of carbon emissions, the total carbon emissions and energy consumption trends from 2000 to 2016 in the Beijing-Tianjin-Hebei region are shown in table 2.

| Year | Energy consumption (million tce) | Carbon emission (million tons) | GDP (billion RMB) | Coal share (%) | Carbon intensity (ton / million RMB) |
|------|----------------------------------|--------------------------------|-------------------|----------------|-------------------------------------|
| 2000 | 190.34                           | 484.08                         | 990.75            | 64.95          | 489                                 |
| 2001 | 195.31                           | 497.76                         | 1114.38           | 65.65          | 447                                 |
| 2002 | 208.70                           | 534.25                         | 1248.40           | 65.71          | 428                                 |
According to the changes in the total carbon emissions from 2000 to 2016, it can be seen that with the increase of GDP in the Beijing-Tianjin-Hebei region, carbon emissions show a significant growth trend. In 2000, the total carbon emissions in this region was 484.08 million tons, growing at an average growth rate of not less than 7% to 1118.81 million tons in 2016. Among them, from 2000 to 2013, carbon emissions have been growing at a relatively fast rate, and from 2013 to 2016, carbon emissions have gradually decreased. Although carbon emissions and energy consumption have been growing most of the time, the carbon intensity during these years has remained steadily decreasing.

3. Extended STIRPAT model

3.1. STIRPAT model

In 1972, Ehrlich and Holden first proposed the I=PAT equation to reflect the impact of human economic activity on environmental stress. In 1994, Dietz et al. established a stochastic model of the I=PAT equation-the STIRPAT model.

\[ I_i = a P_i^b A_i^c T_i^d e_i \]  

(2)

Where \( a \) is the model coefficient, \( b, c, d \) respectively represent the elastic coefficient of environmental impact, population size, average wealth and technical level, and \( e \) is the error term. Firstly, compared with the IPAT model, the STIRPAT model can introduce multiple independent variables. Secondly, STIRPAT is a nonlinear model. The introduction of the index makes the model can be used to analyze the non-equal effects of human factors on the environment.

3.2. Extended STIRPAT model

This paper expands the STIRPAT model to fit the carbon emissions. According to the environmental Kuznets curve theory, there is no linear relationship between economic development and carbon emissions, so it is replaced by quadratic. In the establishment of the extended STIRPAT model, in order to avoid zero or negative indicators, all independent variables are logarithmized. The extended STIRPAT model of this paper is expressed as follows:

\[ \ln C = \ln a + b_1 \ln A + b_2 \ln P + b_3 \ln T + b_4 \ln UR + b_5 \ln ES + b_6 \ln I \]  

(3)

Where \( C \) is the carbon emissions, \( A \) is the average wealth, \( P \) is the population size, \( T \) is the technical level, \( UR \) is the urbanization level, \( ES \) is the energy structure, and \( I \) is the industrial level.
The specific values of the above indicators are shown in table 3.

| Year | Carbon emission (million tons) | Per capital GDP (RMB) | Number of resident population (million) | Carbon intensity (ton / million RMB) | urbanization rate (%) | Coal share (%) | Second industry ratio (%) |
|------|---------------------------------|-----------------------|---------------------------------------|-------------------------------------|-----------------------|----------------|--------------------------|
| 2000 | 484.08                          | 10960.84              | 90.39                                 | 489                                 | 39.06                 | 64.95          | 44.53                    |
| 2001 | 497.76                          | 12262.11              | 90.88                                 | 447                                 | 40.94                 | 65.65          | 43.06                    |
| 2002 | 534.25                          | 13621.43              | 91.65                                 | 428                                 | 43.36                 | 65.71          | 41.90                    |
| 2003 | 595.16                          | 15706.51              | 92.36                                 | 410                                 | 45.11                 | 63.96          | 43.03                    |
| 2004 | 685.14                          | 18895.36              | 93.26                                 | 389                                 | 47.05                 | 63.23          | 44.50                    |
| 2005 | 810.90                          | 22145.11              | 94.32                                 | 388                                 | 49.31                 | 62.51          | 45.16                    |
| 2006 | 864.21                          | 25118.15              | 95.74                                 | 359                                 | 50.53                 | 60.48          | 44.74                    |
| 2007 | 878.19                          | 29491.36              | 97.34                                 | 306                                 | 52.01                 | 60.04          | 43.91                    |
| 2008 | 960.64                          | 34063.99              | 99.36                                 | 284                                 | 53.74                 | 59.92          | 44.43                    |
| 2009 | 1018.48                         | 36465.48              | 101.22                                | 276                                 | 55.48                 | 60.46          | 42.82                    |
| 2010 | 1079.90                         | 41829.08              | 104.55                                | 247                                 | 56.64                 | 57.06          | 43.30                    |
| 2011 | 1172.76                         | 49057.91              | 106.15                                | 221                                 | 57.78                 | 56.40          | 43.80                    |
| 2012 | 1200.53                         | 53248.18              | 107.7                                 | 209                                 | 58.93                 | 57.44          | 43.12                    |
| 2013 | 1207.31                         | 57404.55              | 109.2                                 | 193                                 | 59.66                 | 58.47          | 42.03                    |
| 2014 | 1161.99                         | 60145.58              | 110.53                                | 175                                 | 61.05                 | 57.31          | 41.05                    |
| 2015 | 1154.42                         | 62244.36              | 111.43                                | 166                                 | 62.51                 | 56.34          | 38.40                    |
| 2016 | 1118.81                         | 67492.16              | 112.05                                | 148                                 | 63.88                 | 54.38          | 36.72                    |

4. Analysis of factors affecting carbon emissions

4.1. Cointegration analysis

4.1.1. Unit root test. If the mean, variance, and autocovariance of the time series do not change over time, then the sequence is stable, otherwise it is unstable. If the stability test of the original data is ignored, the result may fall into the dilemma of pseudo-regression. Therefore, it is necessary to perform a stationarity test on the time series, and the unit root test is a method commonly used.

(1) Unit root test of sequence $\ln C_t$

The unit root test is performed on the sequence $\ln C_t$ by the ADF (Augmented Dickey-Fuller) test, and the test results are shown in figure 1. It can be seen that the value of the t statistic is 0.777553, which is larger than the critical value when the significance level is 10%. Therefore, the original hypothesis cannot be rejected and the sequence is non-stationary.
In order to determine whether the sequence $\ln C_i$ is monotonic, the unit root test should be performed on its differential sequence. The first-order difference sequence of $\ln C_i$ is denoted as $i \ln C_i$, and the results are shown in figure 2. The t-statistic value is -3.787347, which is less than the threshold value when the significance level is 10%, so the sequence $\ln C_i$ is a first-order single-sequence, that is, $i \ln C_i \sim I(1)$.

The test results show that the t statistic probability values of sequences $\ln A_i^2$, $\ln P_i$, $\ln UR_i$, $\ln T_i$, $\ln ES_i$ and $\ln I_i$, and the test results are shown in table 4.
In $T_i$, ln $ES_i$ and ln $I_i$ are greater than the test level of 10%, so that sequences ln $A_i^2$, ln $P_i$, ln $UR_i$, ln $T_i$, ln $ES_i$ and ln $I_i$ are considered to be unstable. While the t statistic probability values of the first-order difference sequences $ln A_i^2$, $ln P_i$, $ln T_i$ and $ln ES_i$ of sequences ln $A_i^2$, ln $P_i$, ln $T_i$ and ln $ES_i$ are less than 10%, it is considered that the sequences $ln A_i^2$, $ln P_i$, $ln T_i$ and $ln ES_i$ are stable, that is, $ln A_i^2 \sim I(1)$, $ln P_i \sim I(1)$, $ln T_i \sim I(1)$ and $ln ES_i \sim I(1)$. The t statistic probability values of the second order difference sequences $ii ln UR_i$ and $ii ln I_i$ of sequences ln $UR_i$ and ln $I_i$ are less than 10%, so that sequences $ii ln UR_i$ and $ii ln I_i$ are considered to be stable, that is, $ii ln UR_i \sim I(2)$ and $ii ln I_i \sim I(2)$. Therefore, there may be a long-term stable proportional relationship between the five groups of ln $C_i$, ln $A_i^2$, ln $P_i$, ln $T_i$ and ln $ES_i$, and the next co-integration test is needed.

4.1.2. Cointegration test. If two or more variables are unstable, but some linear combination of them are stable, there is a long-term equilibrium relationship between these variables, namely the cointegration relationship. In this paper, the Johansen test is used to test whether there is a cointegration relationship between the five sequences ln $C_i$, ln $A_i^2$, ln $P_i$, ln $T_i$ and ln $ES_i$.

![Table 3. Trace test results.](image)

In figure 3, under the original hypothesis “At most 4”, the calculated trace statistic value is 1.169114, which is less than the critical value of 4.129906. Therefore, it is acceptable to assume the null hypothesis that there are four cointegration relationships at the 5% significance level.

4.2. Error correction model

It has been proved above that there is a cointegration relationship between the five sequences ln $C_i$, ln $A_i^2$, ln $P_i$, ln $T_i$ and ln $ES_i$. Therefore, an error correction model can be established to study the relationship between actual carbon emissions and economic level, population size, technical level and energy structure. The error correction model and related test results are shown in figure 4.

![Figure 4. ECM estimation and related test results.](image)
The error correction model can be obtained as follows:

\[
\ln C_i = -16.09922 - 0.566606 \ln C_{i-1} + 0.511013 \ln A^2_i + 0.258143 \ln A^2_{i-1} \\
+ 1.033811 \ln P_i + 0.891859 \ln P_{i-1} + 1.091137 \ln T_i + 0.546814 \ln T_{i-1} \\
+ 0.130283 \ln ES_i + 0.215060 \ln ES_{i-1} + \varepsilon_i 
\]

The short-term changes in carbon emissions can be divided into two parts. The first part is due to changes in the current economic level, population size, technology level and energy structure. For each additional unit of \( \ln A^2 \) this year, the \( \ln C \) of this year will change by 0.511013 units in the same direction, that is, the short-term elasticity of carbon emissions to the economic level is 0.511013. For each additional unit of \( \ln P \) this year, the \( \ln C \) of this year will change by 1.033811 units in the same direction, that is, the short-term elasticity of carbon emissions to the population size is 1.033811. For each additional unit of \( \ln T \) this year, the \( \ln C \) of this year will change by 1.091137 units in the same direction, that is, the short-term elasticity of carbon emissions to the technical level is 1.091137. For each additional unit of \( \ln ES \) this year, the \( \ln C \) of this year will change by 0.130283 units in the same direction, that is, the short-term elasticity of carbon emissions to the energy structure is 0.130283.

The second part is due to the changes in carbon emissions, economic level, population size, technology level and energy structure in the previous period. For each additional unit of \( \ln C \) of the previous year, the \( \ln C \) of this year will change by 0.566606 units in the opposite direction. For each additional unit of \( \ln A^2 \) of the previous year, the \( \ln C \) of this year will change by 0.258413 units in the same direction. For each additional unit of \( \ln P \) of the previous year, the \( \ln C \) of this year will change by 0.891859 units in the same direction. For each additional unit of \( \ln T \) of the previous year, the \( \ln C \) of this year will change by 0.546814 units in the same direction. For each additional unit of \( \ln ES \) of the previous year, the \( \ln C \) of this year will change by 0.21506 units in the same direction.

5. Conclusion

This paper first analyzes the carbon emissions of energy consumption in the Beijing-Tianjin-Hebei region. Secondly, the improved STIRPAT model is used to analyze the influencing factors of carbon emissions from energy consumption. Then, using the cointegration and error correction model to study the long-term equilibrium relationship and short-term change between the carbon emissions and its influencing factors in Beijing-Tianjin-Hebei region. The results show that an increase in per capita GDP and population will increase carbon emissions, while the optimization of energy structure and technology will contribute to the reduction of carbon emissions. From the perspective of the impact on carbon emissions, the contribution of the technical level is the largest, the contribution of the economic level is second, and the contribution of the population size is the weakest.

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