Investigating the Influencing Factors of Carbon Dioxide Emissions from Residents' Energy Consumption in China

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Abstract. With the rapid development of the social economy and the accelerated process of urbanization, the consumption level of residents, especially the demand of energy consumption has increased greatly, which will become an important reason for the growth of carbon dioxide emissions in the future. China has concentrated on policies and measures for energy conservation and emission reduction in the industrial and industrial sectors, ignoring the issue of carbon emissions in the residents’ consumption for a long time. This paper calculates the carbon dioxide emissions of residents’ energy consumption for 1991-2017 based on thirteen kinds of energy consumption. Then constructing the STIRPAT model to divide the influence factors into 5 factors: population, urbanization rate, GDP per capita, energy structure and energy intensity. This paper constructed the cointegration equation and the VEC model through the unit root test, Johansen cointegration test and Grainger causality test by Eviews8 software. Finally, this paper purposed the measures of reducing the carbon dioxide emissions of residents' energy consumption by reducing the carbon dioxide emissions per capita and adjusting the energy structure.

1. Introduction

The massive consumption of fossil energy such as coal and oil has increased the content of greenhouse gases in the atmosphere, while driving the development of the world economy. The consequences of global climate warming will seriously damage the living environment of human beings and pose a huge threat to the survival and development of mankind. The excessive greenhouse gas emissions and various environmental problems become the focus of attention of all countries in the world. As a big developing country, China is in a critical period of social development and economic construction. The rapid growth of the economy and the accelerating process of industrialization and urbanization make China's energy demand and carbon dioxide emissions show a sharp rise. At the Copenhagen Climate Conference in 2009, China proposed to reduce 40%-45% carbon emissions per unit GDP by 2020. In 2015, China raised the carbon emission reduction target to 60%-65%, and proposed to achieve peak carbon emissions by 2030 or earlier.

China has focused on energy saving and emission reduction policies and measures in the industrial sector and industrial sector in past several years, ignoring the CO₂ emissions in the civil consumptions. However, with the continuous improvement of living standards and residential area, the consumption of household appliances and private vehicle rose. Natural gas, electricity and liquefied gas has replaced traditional energy in large quantities, which ultimately leads to the increasing consumption of household...
energy and corresponding emissions. Therefore, the contribution of residents’ consumption to the total CO2 emissions cannot be ignored. At the same time, energy saving and emission reduction in industrial sector is no longer the only way to achieve low-carbon development in China, as the marginal benefits of energy saving and emission reduction technology in industrial sector are gradually decreasing.

Researchers has proved that the proportion of carbon emissions from household consumption in the total carbon emissions should not be ignored, which has increased rapidly. Yan et al. concluded that the proportion of carbon emissions from household consumption increased from 19% in 1995 to 30% in 2004 [1]. Zhu Qin et al. pointed out that residents’ consumption carbon emissions have become one of the main sources of carbon emissions in China [2]. In foreign studies, Kim et al. indicated that the population densities decreased the carbon footprint of the residents [3]. To sum up, most studies have confirmed that resident consumption will become an important source of energy demand growth and dioxide emission growth in the future, especially resident energy consumption. Accordingly, this paper aims to tap the potential of energy saving and emission reduction in residents’ energy consumption through the analysis of influencing factors in carbon dioxide emissions.

2. Experimental

2.1. Data Conversion and Calculation of CO2 Emissions
Residents’ carbon dioxide emissions mainly due to fossil fuels directly consumed and indirect power and thermal production processes. Carbon dioxide emission from household energy is mainly calculated by the carbon emission coefficient method, which assumed that the carbon emission coefficient of a certain energy is fixed according to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. This paper takes 13 energy types and energy consumption of greenhouse gas emissions, including raw coal, coal washing, briquette, coke, coke oven gas, other gas, gasoline, kerosene, diesel, liquefied petroleum gas, natural gas, heat and electricity from the energy balance table of China’s Energy Statistics Yearbook 1991-2017.

The carbon dioxide emission of the primary fossil energy can be calculated directly by inquiring the IPCC coefficient as shown in Eq. (1).

\[
C_1 = \sum_j AC_j \times NCV_j \times f_j
\]  

(1)

Where \( C_1 \) is CO2 emissions from primary energy consumption of residents, \( j \) is direct consumption of fossil fuels, \( AC \) represents for the physical quantity of primary energy consumed by residents, \( NCV \) means low calorific value of fuels, \( f \) is carbon emission coefficient.

Thermal and electric power are secondary energy sources. The calculation of carbon emission coefficient needs to decompose the composition of fossil energy. The amount of CO2 emission from residential energy consumption is the sum of primary energy consumption, electricity consumption and thermal energy consumption.

![Figure 1. CO2 emissions from energy consumption of residents](image-url)

Fig. 1 shows the total emission of CO2 from energy consumption. It is shown that, from 1991 to 1999, domestic energy CO2 emissions fluctuated, even decreased slightly from 1996 to 1998. However,
after 2000, energy consumption carbon dioxide emissions increased greatly. In 2017, the carbon dioxide emissions increased by 2.17 times compared with 2000, with an average annual increase of 49.358 million tons. Urban carbon dioxide emissions increased relatively fast, and the proportion of carbon dioxide emissions of urban residents to the total amount of carbon dioxide emissions increased by 3 percentage points. This is related to the rapid development of urbanization in China, and the continuous improvement of living standards of urban residents.

2.2. STIRPAT model
STIRPAT model is a stochastic environmental impact assessment model modified based on IPAT model, which is used to explore the relationship between economic activity and environmental pressure. The model shows that environmental change is mainly affected by population (P), wealth (A) and technology (T) and assumes that the elasticity of all driving factors is equal to 1, leading to the environmental pressure is affected equally by various factors. Therefore, York et al. modified the IPAT model and proposed the STIRPAT model that shown in Eq. (2) [4].

\[
Y = a \times P^b \times A^c \times T^d \times e
\]  

(2)

Where \(I\) the total amount of CO2 emission, \(a\) represents the intercept term, the \(b, c,\) and \(d\) are the coefficients of environmental effects with respect to \(P, A,\) and \(T,\) and \(e\) means the random error term.

According to the previous research, population is one of the driving factors of carbon dioxide emissions from residential energy use. As a large population country, population cannot be ignored in the analysis of from residential carbon emissions. The urbanization rate indicates the degree of rural population transferring to the city, which bring about changes in residents direct energy consumption. Many scholars have verified that the urbanization rate has a higher impact on carbon emissions. Per capita GDP represents people’s living standards, the improvement of which will lead to increasing of energy consumption as well as the growth of carbon emissions. The structure of residential energy consumption reflects the level of energy supply in China, which is expressed by the proportion of coal consumption in residential direct energy consumption. Energy intensity is the index of technology level and energy efficiency, which is reflected by energy consumption per unit GDP. To sum up, taking logarithms on both sides of the equation, the STIRPAT model of resident consumption carbon emissions is constructed as Eq. (3).

\[
\ln Y = \ln a + a_1 \ln P + a_2 \ln U + a_3 \ln G + a_4 \ln ES + a_5 \ln EI + \ln e
\]  

(3)

Where \(P\) is population, \(U\) is urbanization, \(G\) is per capita GDP, \(ES\) is energy structure, \(EI\) is energy intensity.

2.3. Econometric model
VAR model is an unstructured model with multiple equations, which regards each exogenous variable as a function of the lag value of the endogenous variable. The VAR model examines the dynamic interaction among multiple variables, and constructs the regression model by taking the endogenous variables as functions of lag terms. The general form is as Eq. (4).

\[
\begin{align*}
Y_t &= A_1 Y_{t-1} + A_2 Y_{t-2} + \cdots + A_p Y_{t-p} + \varepsilon_t \\
Y_t &= A_1 Y_{t-1} + A_2 Y_{t-2} + \cdots + A_p Y_{t-p} + \varepsilon_t
\end{align*}
\]  

(4)

where \(Y\) is endogenous variables, \(A\) denotes the corresponding coefficient matrix, and \(P\) represents the delay order of endogenous variable.

As VAR model can only be used to analyze the effects of long-term relationships rather than the short-term fluctuations among variables, some scholars combined co-integration with error correction model to construct Vector error correction model. VEC model incorporates an error correction term into the VAR model established by the difference sequence, which formula is shown in Eq. (5).

\[
\Delta Y_t = \alpha ECM_{t-1} + A_1 \Delta Y_{t-1} + A_2 \Delta Y_{t-2} + \cdots + A_p \Delta Y_{t-p} + \varepsilon_t
\]  

(5)

Where ECM represents the error correction term calculated by the co-integration equation, which reflects the non-equilibrium error between variables deviating from the long-term equilibrium relationship. \(A\) is the adjustment coefficient, which is used to reflect the speed at which the current
change of variables returns to the long-term equilibrium relationship or eliminates the non-equilibrium error.

3. Results

3.1. Multiple collinearity test and unit root test
The results of multivariate linear regression for various factors by ordinary least squares method are not significant. The VIF value of the collinear statistics is greater than 20, indicates that there are serious multicollinearities among independent variables, and the general regression model cannot be used.

As all explanatory variables belong to time series, ignoring the stationarity of the original data may lead to pseudo-regression. This paper uses ADF unit root method to test the stability of variables, and the data are tested on the basis of guaranteeing the white noise characteristics of random interference terms.

The results of ADF unit root test in table 1 shown that the corresponding probabilistic values of all first-order differential sequences are less than 10% of the test level, so the sequence can be considered to be stationary.

Table 1. Results of ADF unit root test

| Variable | ADF  | p-value | Results | Variable | ADF  | p-value | Results |
|----------|------|---------|---------|----------|------|---------|---------|
| lnY      | 0.0281 | 0.9524  | Unstable | D(lnY)   | -2.9489 | 0.0545  | Stable  |
| lnP      | 1.2809 | 0.9977  | Unstable | D(lnP)   | -2.7472 | 0.0810  | Stable  |
| lnU      | -1.2947 | 0.06517 | Unstable | D(lnU)   | -3.6800 | 0.0122  | Stable  |
| lnG      | -0.6176 | 0.8489  | Unstable | D(lnG)   | -4.1917 | 0.0037  | Stable  |
| lnES     | -0.4677 | 0.8785  | Unstable | D(lnES)  | -4.9749 | 0.0008  | Stable  |
| lnEI     | -0.7961 | 0.8013  | Unstable | D(lnEI)  | -3.1513 | 0.0366  | Stable  |

The results of ADF unit root test in table 1 shown that the corresponding probabilistic values of all first-order differential sequences are less than 10% of the test level, so the sequence can be considered to be stationary.

3.2. Determination of lag order of VAR model
The appropriate lag time should be chosen for VAR model. The larger the lag number is, the better the dynamic characteristics of the constructed model can be reflected. However, while the lag time become large, the degree of freedom of the model will be smaller, which will directly affect the validity of the parameters of the estimation model. The lag order of the model can be determined according to the principle that the AIC or SC value is the smallest.

The results of Johansen cointegration test can be used to determine whether there is a cointegration relationship between variables.

3.3. Johansen cointegration test
The results of Johansen cointegration test shows that the statistic value of trace under the original hypothesis is 186.6173, greater than the critical value at the level of 5%, indicates that there is at least one cointegration relationship. Continue to carry out the next test until the last refusal of the 5th
hypothesis, five co-integration relationships among the six variables are found, proved that there was a long-term relationship between the variables.

\[
\ln Y = 4.00612 \ln U + 5.903765 \ln P + 0.396355 \ln G + 0.921975 \ln ES + 1.418033 \ln EI \tag{6}
\]

Cointegration equation in Eq. 9 shows that CO2 emissions is positively correlated with other variables in the long run. Resident population factors have the greatest impact on CO2 emissions followed by urbanization rate. Every 1% increase in population, CO2 emissions will raise for 5.9%. The adjustment coefficient before variable is negative, showing that the co-integration relationship is effective.

3.4. Estimation of VEC Model

As the variables pass Johansen cointegration test, VEC model can be constructed as follows:

\[
\begin{bmatrix}
D(\ln Y) \\
D(\ln U) \\
D(\ln P) \\
D(\ln G) \\
D(\ln ES) \\
D(\ln EI)
\end{bmatrix}
= 
\begin{bmatrix}
-0.40 & -1.60 & 0.60 & 0.61 & 0.02 & -0.80 \\
0.02 & 0.61 & -0.34 & -0.11 & -0.06 & 0.09 \\
0.02 & -0.01 & 0.57 & 0.03 & 0.01 & 0.07 \\
0.01 & -0.16 & 6.85 & 0.67 & 0.04 & 0.08 \\
0.51 & 0.48 & -95.5 & 1.18 & 0.26 & 1.63 \\
-0.31 & 0.86 & -22.8 & 0.28 & 0.21 & 1.14
\end{bmatrix}
\begin{bmatrix}
D(\ln Y) \\
D(\ln U) \\
D(\ln P) \\
D(\ln G) \\
D(\ln ES) \\
D(\ln EI)
\end{bmatrix}_t
+ 
\begin{bmatrix}
0.13 & 0.35 & 0.02 & -0.02 & -0.04 & -0.02 \\
0.13 & 0.02 & 0.03 & -0.04 & -0.02 & -0.01 \\
0.13 & 0.03 & 0.03 & -0.02 & -0.03 & -0.04 \\
0.13 & 0.01 & 0.06 & -0.01 & -0.03 & -0.01 \\
0.13 & 0.02 & 0.01 & -0.04 & -0.03 & -0.04 \\
0.13 & 0.04 & 0.01 & -0.03 & -0.04 & -0.03
\end{bmatrix}C_{t-1} \tag{7}
\]

The first coefficient of error correction \(C_{t-1}\) is 0.13, which indicates that the change of \(\ln Y\) in t period will increase the error of 12.7% in the previous period when the other variables remain unchanged. The fourth coefficient -0.04 indicates that the variation of \(\ln G\) in t period can eliminate the error of 3.9% in the previous period when the other variables remain unchanged. The unit root test results of VEC model show that there is no unit root greater than 1, so the established VEC model is stable.

4. Discussion

The influencing factors of carbon dioxide emissions from domestic energy use in China from 1991 to 2016 are population factor, urbanization rate, energy structure, energy intensity and per capita GDP sequentially, according to the degree of their influence.

Population has a greater impact on carbon dioxide emissions. China has implemented various policies to reduce population growth rate. Since 1990, China’s population growth rate has dropped from 1.16% to 0.59%. However, the decline rate of population growth rate has slowed down and it is difficult to further inhibit the growth rate of carbon emissions. From another point, reducing per capita carbon dioxide emissions through energy saving in daily lives can reduce the impact of population growth on carbon dioxide emissions and effectively slow down the growth rate of carbon dioxide emissions. Therefore, measures such as building green residential areas and enhancing residents’ awareness of emission reduction will be useful.

Urbanization rate has a greater impact on carbon dioxide emissions. With the improvement of urbanization rate as well as living standards of residents, residents consume more energy. In addition, the acceleration of urbanization makes the mobility rate of residents larger, brings more traffic energy consumption, and carbon dioxide emissions rise faster. However, the urbanization rate has a greater role in promoting the change of people’s lives, so it is difficult to reduce the carbon dioxide emissions through the change of urbanization rate.

Energy structure has a great impact on per capita carbon dioxide emissions, that is, the carbon dioxide emissions of energy consumption will increase by 1.42% if the proportion of coal consumption increases by 1%. Compared with natural gas and petroleum energy, the thermal efficiency of coal energy is low and the carbon emission coefficient is large. The carbon dioxide emission per unit coal consumption is much larger than that of oil or natural gas consumption, leading to positively correlation between coal consumption carbon dioxide emission. The carbon dioxide coefficient of electricity consumption and heat is larger than that of coal consumption, as coal consumption is the main source of heat supply and power generation in China. Therefore, power energy demand may lead to an increase in carbon emissions. However, with the improvement of power structure, the proportion of clean energy power generation began to rise, which decrease the demand for coal energy on power generation side. Carbon
dioxide emissions from power consumption would be reduced, so reducing the proportion of coal use would reduce carbon dioxide emissions.

Energy intensity and per capita GDP have less impact on carbon dioxide emissions. Energy intensity represents the impact of technological progress on the carbon dioxide emissions of household energy consumption in China. Per capita GDP is a measure of economic level. That is, China's technological progress or economic development brings convenience in energy use, stimulates residents to consume more energy, thus increasing carbon dioxide emissions, but the impact is not obvious.

5. Conclusion
This paper calculates the carbon dioxide emissions of residents’ energy consumption from 1991 to 2017, based on thirteen kinds of energy consumption. The results show that the carbon dioxide emissions by residents in China have increased significantly. It is necessary to analyse the influence factors of residents’ carbon dioxide emissions to formulate emission reduction measures.

Then in this paper, STIRPAT model is constructed to divide the influencing factors of carbon dioxide emissions into five factors: population, urbanization, per capita GDP, energy structure and energy intensity. Through the analysis of five variable time series, the influence of factors is judged by the unit root test, VAR lag test and cointegration test. Finally, the cointegration equation and VEC model are constructed. Results shows that there are many co-integration relationships among variables, which indicates that the explanatory variables have a long-term relationship with carbon dioxide emissions.

In conclusion, measures to reduce carbon dioxide emissions from residents’ energy consumption mainly depend on reducing per capita carbon dioxide emissions and adjusting energy structure to reduce coal consumption. Resident carbon emissions are complex multi-factor system problem that deserves deeply study. Embedded carbon emissions of consumer goods also account for a larger proportion of resident carbon emissions to further reduce carbon emissions.

Acknowledgments
This paper is supported by the Social Science Foundation of Beijing (Project ID 15JGB050).

References
[1] Wei, Y., Liu, L., Fan, Y., Wu, G. (2005) The impact of lifestyle on energy use and CO2 emission: an empirical analysis of China's residents. Energy Policy, 35: 247-257.
[2] Yan, W, Minjun, S. (2009) CO2 emission induced by urban household consumption in China. Chinese Journal of Population Resources and Environment, 7: 11-19.
[3] Taehyun, K., Hongkyu, K. (2013) Analysis of the effects of intra-urban spatial structures on carbon footprint of residents in Seoul, Korea. Habitat International, 38: 192-198.
[4] York, R., Rosa, E., Dietz, T. (2003) STIRPAT, IPAT and IMPACT: analytic tools for unpacking the driving forces of environmental impacts. Ecological Economics, 46:351-365.
[5] Liu, L., Wu, G., Wang, J., Wei, Y. (2011) China's carbon emissions from urban and rural households during 1992-2007. Journal of Cleaner Production, 19:1754-1762.
[6] Zhu, Q., Peng, X., Wu, K. (2012) Calculation and decomposition of indirect carbon emissions from residential consumption in China based on the input-output model. Energy Policy, 48: 618-626.