China's Energy Consumption and Economic Growth under the Constraints of Carbon Emissions

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Abstract: This paper was based on the provincial unbalanced panel data of 31 administrative regions in China from 2005 to 2016, investigated the effects of carbon emission constraints and economic growth on China's energy consumption, energy consumption structure and energy policy changes. The empirical results showed that a higher level of economic development would increase regional carbon emissions. Active energy policy and consumption structure adjustment will have a significant inhibitory effect on carbon emissions. This study provided micro-theoretical support for the optimization of regional energy consumption structural adjustment strategy, spatial prediction of emission reduction, and resolving the balance between energy supply and demand. It was helpful for local governments to analyze the energy consumption situation and the overall structural change trend according to the energy consumption structure. It could further tap the energy-saving potential of the region and formulate reasonable long-term development strategies.

1. Introduction
Carbon cycle is one of the basic driving forces of global climate and environmental change. With the continuous development of social economy, the exchange scale and rate of matter energy in land surface systems are increasing. The asymmetry development of global has brought about significant negative effects on global climate and environment. In recent years, with the rapid development of China's economy, carbon emissions have attracted wide attention due to huge energy consumption and environmental pressures. In the past two decades, energy standard coal consumption has increased from 1.46 billion tons in 2000 to 3.25 billion tons in 2010, and then to 4.36 billion tons in 2016. The emission reduction strategy has also developed from simple low-carbon and new energy to more specific and instructive capacity removal and gradually adapted to the new normal economy. In the government report of 2017, Premier Li Keqiang clearly proposed expanding the work of cutting overcapacity into the field of coal and electricity, and formulated the energy consumption target of 2017, the coal consumption target and the specific targets of eliminating, suspending and delaying the construction of coal and electricity production capacity. The above-mentioned central decision-making and government actions fully reflect the central government's determination to implement the emission reduction strategy and provide a good institutional environment basis.

2. Theoretical Analysis and Literature Review
In the study of the influencing factors of the change of energy consumption structure, Gabriel et al. (2001), Tol (2007) and other scholars built a complete macro-model earlier, and analyzed the influencing factors of the change of energy consumption structure. Nakata (2004) extends the study on the external environmental impact of energy consumption structure, and considers that the adjustment
of energy consumption structure should take into account the impacts on economic, population growth and environmental, and points out the importance of renewable energy development for green economy. Li et al. (2012) further assessed the development potential and sources of green energy in a region in two scenarios, and on this basis analyzed the contribution potential of green energy in achieving carbon intensity targets. There are many variables affecting the structure of energy consumption, so far, the academic community has not reached a consistent conclusion. From the direct impact factor analysis, regional population, industrial structure, resident consumption level and other aspects will affect energy consumption demand, indirect factors mainly include domestic or regional gross domestic product, proportion of industrial output value, national or regional gross energy product, total energy import value, energy efficiency and so on. In the further study of the influencing factors, Lin Boqiang et al. (2009, 2010) constructed a co-integration model based on energy consumption and GDP, urbanization level, industrial structure, energy price and energy efficiency, and used scenario analysis method to calculate the energy consumption structure under various scenarios, pointing out the key influencing factors and feasible paths for the development of low-carbon economy. Fan Decheng et al. (2012), Ye Yuyao et al. (2014) and Li Shuang et al. (2015) measured the impact of various external factors on energy consumption structure under the low-carbon economic target from a more macro perspective. As far as research methods are concerned, considering the complex conduction mechanism of energy consumption structure change, its changing law is affected by internal and external factors, and the interaction of various factors may also form a variety of complex influence paths and make the variables appear multiple collinearity. In order to eliminate the impact of collinearity on regression results, Zeng Fanhua (2013), Dai Hongjun (2016) uses ridge regression analysis method to fit, and achieves a more realistic and reliable estimation of morbid data by losing a small amount of information. Generally speaking, the adjustment of energy structure is a systematic project, which needs to take into account the economic development, resource endowment, population status, industrial structure and policy environment of the region in an all-round way.

In summary, scholars have used various methods to study the optimization of energy consumption structure. They have gone through the analysis of influencing factors based on theoretical model to the feasibility demonstration of structural adjustment based on empirical level, from the trend prediction of energy structure change at the policy level to the evaluation of low-carbon effect closer to the people's livelihood. The existing achievements have maturity in both theoretical research and empirical support, and have relatively stable conclusions in many research units, and have the conditions for expanding application in regional socio-economic development.

3. Empirical Analysis and Discussion

3.1. Research methods and modeling

In order to improve the reliability of the model, incorporate the total energy, energy consumption structure, industrial structure, GDP, total population and policy variables into the general relationship between energy structure and carbon emissions. Construct a state-space variable parameter model of the impact of energy structure adjustment on carbon emissions as follows:

$$\ln C = a_0 + a_1 \ln toen + a_2 \ln enst + a_3 \ln engdp + a_4 \ln inst + a_5 \ln pop$$

$$+ a_6 \ln gdp + a_7 \ln gdp2 + a_8 \ln gdp3 + a_9 \ln policy + u$$

(1)

Formula (1) is the measurement equation of the model, which reflects the relationship between the explained variable and all explanatory variables. Toen represents the total energy consumption, enst represents the adjustment of energy consumption structure, engdp represents the energy intensity of the region, Inst represents the industrial structure, GDP represents the economic development level of the region, pop represents the total population, policy represents the policy variable, u is the random perturbation term. In order to measure the quantitative relationship of percentage changes among variables, all variables (except policy variables) are in the form of natural logarithms. Considering the possible inverted U-shaped effect of economic growth on carbon emissions, incorporate the square
term ln GDP2 and cubic term ln GDP3 of GDP to the numerical value into the formula.

3.2. Data Sources and Processing
This paper chooses the provincial unbalanced panel data from 2005 to 2016 as a sample to study the relationship between energy consumption structure and emission reduction, which removes the administrative regions such as Tibet, Hong Kong and Macao where data are difficult to obtain or lack seriously. The starting date of the sample is 2005, which is due to the significant changes in the world energy pattern in 2005. The frequent rising oil prices have led many countries to adjust their energy policies substantially and adopt energy-saving or expansion of energy development structure to solve the problem of energy prices. On the other hand, in the context of the domestic coal, oil and electricity shortages, the State Council established the National Energy Leading Group in May 2005 as the highest-level deliberative and coordinating body for energy work. As a result, the State Council's "large-ministerial system reform" has merged the nuclear power management functions of the State Development and Reform Commission's Energy Bureau, the State Energy Leading Group and the former National Defense Science and Technology Commission, and the State Energy Administration has been officially listed and put into operation. Therefore, 2005 is an important turning point in China's energy development. After 2005, various regions began to carry out phased energy reform. The data mainly come from China Energy Statistics Yearbook, China Statistics Yearbook and the websites of provincial statistical bureaus. The measurement and data processing of variables are described as follows:

Carbon emissions are the explained variable in this study. The commonly used method is based on the calculation method of Volume II (Energy Volume) of IPCC Guidelines for National Greenhouse Gas Inventories. The formula is as follows:

\[
C = \sum C_i = \sum E_i \times NCV_i \times CC_i \times COF_i \times \frac{44}{12}
\]

Among them, \(i\) is a positive integer, indicating the type of energy, \(C\) represents the total amount of carbon dioxide emissions, \(E\) represents energy consumption, \(NCV\) is the average low calorific value, \(CC\) represents the carbon level per unit calorific value, \(COF\) is the carbon oxidation factor, that is, the carbon oxidation rate when energy burns, 44 and 12 respectively represent carbon dioxide and the molecular weight of carbon.

This study mainly focuses on carbon emissions at the national level. China Energy Statistics Yearbook statistics primary energy consumption in four types of energy. The data show that the carbon dioxide emission coefficients of coal, oil, natural gas and water, nuclear and wind power respectively are 2.745, 2.146, 1.629 and 0. Therefore, from the availability and reliability of data, it is easier to use another calculation method to achieve the research purpose. The specific formula of calculation is as follows:

\[
C = \sum E \times (e_i / E) \times c_i
\]

In this expression, \(E\) represents China's total primary energy consumption (converted into 10,000 tons of standard coal), \(e_i / E\) is the proportion of energy in category \(i\), and \(c_i\) is the carbon dioxide emission coefficient of energy in category \(i\).

3.3. Empirical test and Result analysis
Table 1 shows the unit root test results of explanatory variables, explained variables and their corresponding differential variables. The statistical value of the final test is less than the critical value to indicate that the data is stationary, and greater than the critical value to indicate non-stationary. From the test results, it can be found that most of the original explained variables in the unit root test, the test statistic \(z(t)\) value is greater than the critical value at any significant level, indicating that the original variable data sequence is not stable, therefore, conduct first-order difference of variables. The results show that the statistic value of the ln C first-order difference variable dln C is -3.013, which is greater than the critical value of -3.709 at the level of 1% significance and less than the critical value of -2.983 at the level of 5% significance. It shows that the first-order difference variable of ln C is
stable at the level of 5% significance. Conduct other variables to similar stationarity tests, except for the $\text{lnpop}$ second-order difference variable $\text{ddlnpop}$, other variables are all achieved that the data sequence of first order difference is stable, which means that the second-order difference sequence of all variables is stable.

Table 1 Unit Root Test Results of explanatory variables and explained variables

| variable    | statistic $z(t)$ | p-value |
|-------------|-----------------|---------|
| $\text{lnC}$ | 0.397           | 0.9723  |
| $\text{dlnC}$ | -3.013         | 0.0289  |
| $\text{dlntoen}$ | -6.287      | 0.0000  |
| $\text{dlnenst}$ | -3.512       | 0.0097  |
| $\text{dlninst}$ | -3.133        | 0.0198  |
| $\text{ddlnpop}$ | -7.126        | 0.0000  |
| $\text{dlnengdp}$ | -5.973       | 0.0000  |
| $\text{dlngdp}$ | -2.973         | 0.0683  |
| $\text{dlngdp2}$ | -5.379        | 0.0000  |
| $\text{dlngdp3}$ | -11.637        | 0.0000  |

From the regression results, we can find the following conclusions. After the adjustment of energy structure, the explanatory coefficients of total energy consumption and energy structure variables are all decreasing. Although the range is small, it can be explained to some extent that the supply of energy structure policy at the national level makes the energy structure of different regions converge to a certain extent, and the relationship between carbon emissions and the two variables in different provinces is no longer as significant as before. The coefficient of industrial structure variables is not significant, which indicates that the increase of the proportion of tertiary industry in the region has no significant impact on the decline of carbon emissions. The reason may be that with the development of economy, the economic contribution efficiency of the tertiary industry is increasing. In this process, the carbon emissions of the primary and secondary industries may not necessarily decrease, or even increase, and the tertiary industry itself may also increase regional carbon emissions. For the relationship between energy intensity and carbon emissions, the coefficient is significant at the level of 10%, which shows that better energy intensity can reduce regional carbon emissions to a certain extent. However, after the policy adjustment after 2012, all regions pay more attention to emission reduction, and the emission reduction effect of energy intensity decreases, which is also reflected in the coefficient test results of the policy. Population and economic growth also show a significant positive correlation with carbon emissions, which is consistent with the conclusions of previous studies.

Table 2 Fixed-effect model

| explanatory variable | total sample | sample before adjustment | adjusted sample |
|----------------------|-------------|--------------------------|-----------------|
| $\text{lnnten}$     | -0.613***   | -0.627***                | -0.497***       |
|                      | (-8.732)    | (-9.120)                 | (-6.533)        |
| $\text{lnenst}$     | -0.136***   | -0.145***                | -0.113***       |
|                      | (-3.569)    | (-3.964)                 | (-2.071)        |
| $\text{lninst}$     | -0.012      | -0.013                   | -0.012          |
|                      | (-0.430)    | (-0.451)                 | (-0.427)        |
| $\text{lnengdp}$    | -0.137*     | -0.142*                  | -0.135          |
|                      | (-1.671)    | (-1.713)                 | (-1.591)        |
| $\text{lnpop}$      | 0.259**     | 0.262**                  | 0.237*          |
|                      | (2.017)     | (2.237)                  | (1.933)         |
| policy               | 0.031*      | 0.021                    | 0.025           |
|        | (1.813) | (1.260) | (1.293) |
|--------|---------|---------|---------|
| lngdp  | 2.132***| 2.390***| 2.017***|
|        | (5.337) | (6.189) | (5.033) |
| lngdp2 | 0.667*  | 0.531   | 0.445   |
|        | (1.732) | (1.370) | (1.113) |
| lngdp3 | 0.009   | 0.009   | 0.007   |
|        | (0.023) | (0.019) | (0.018) |
| cons   | 0.782***| 0.749***| 0.643***|
|        | (4.620) | (4.122) | (3.428) |

Explanation: *, ** and *** respectively indicate that the statistical values of coefficients have passed the significance test at the levels of 10%, 5% and 1%.

4. Conclusions and Policy Recommendations

This study examines the impact of energy consumption, energy consumption structure changes and energy policy changes on carbon emission reduction through empirical testing of provincial panel data of 31 administrative regions in China from 2005 to 2016. The empirical results show that the reform of energy policy has achieved remarkable results in the short term, and the cleaner energy consumption structure can significantly affect carbon emissions. After 2012, after the unified energy consumption reform at the national level, this remarkable degree has declined slightly as a whole due to the improvement of areas with poor energy consumption structure before, but it can still fully explain carbon emissions. Therefore, we can conclude that although carbon emissions are affected by many factors, the reform of energy consumption structure can play a significant emission reduction effect.

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