Research on the Relationship Between Energy Consumption, Economic Growth and Carbon Emissions in China——Based on The System GMM Model

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Abstract. Under the current climate change and economic fluctuations, studying the relationship between economic growth, energy consumption and carbon emissions has become a vital issue for the high-quality economic development of various countries. This paper selects the provincial data from 2004 to 2019, and constructs a dynamic simultaneous equation system. Based on the analysis of the impact of economic growth and energy consumption on carbon emissions, the system GMM estimation is used to empirically test the dynamic relationship between the three and analyze it. The heterogeneity of the relationship at the regional level was analyzed, and then a fixed-effects model was used to test the robustness. The results show that: (1) Under the full sample, energy consumption drives the increase of carbon emissions, and economic growth and industrial upgrading are conducive to realizing carbon emission reduction goals. (2) There is a two-way causal relationship between energy consumption and carbon emissions. (3) There is a two-way relationship between energy consumption, economic growth, and carbon emission in the middle and eastern regions. The economic growth in eastern China drives the increase in carbon emissions. In the central region, carbon emission has a certain restraint effect on economic growth. The model has a certain stability, and provides a useful reference for the coordinated development of China's economic growth, energy consumption, and carbon emissions.

Keywords: Carbon Emission, Economic Growth, Energy Consumption, System GMM.

1. Introduction

The rapid advancement of global industrialization and urbanization has brought about rapid economic growth in various countries. It has promoted the increase of energy demand, increasing carbon dioxide and other endothermic greenhouse gas emissions year by year, and the strengthening of the greenhouse effect. A series of severe weather events, such as forest fires and sea-level rise, threaten the survival and development of human beings. In order to cope with the difficult situation, the "14th Five-Year Development Goal" was put forward at the Fourth Session of the Thirteenth National People's Congress, which pointed out that it is necessary to improve the dual control system of total energy consumption and intensity, focus on controlling fossil energy consumption, and implement the 2030 response to climate change The national independent contribution target, the "14th Five-Year Plan for Circular Economy Development" pointed out that it is necessary to promote the development of circular economy and build a green, low-carbon and circular economic system. The contradiction between the increase in fossil energy consumption caused by economic growth and the increase in carbon emissions brought about by it and the original intention of economic development is related to the direction and trend of future economic development, as well as the sustainability of social and economic development [1]. Therefore, studying the internal relationship between energy consumption, economic growth and carbon emissions is the key to achieving sustainable economic development.

This paper collects provincial panel data from 2004 to 2019, constructs a dynamic panel model, and uses the systematic GMM method to conduct a systematic and comprehensive quantitative analysis of the relationship between energy consumption, economic growth and carbon emissions in my country, and draws the policy enlightenment for my country to achieve sustainable economic development. The main contributions of this paper are as follows: First, the data contribution, the current related research mainly focuses on the overall research at the national level. However, this paper is aimed at specific 29 provinces, from 2004 to 2019, intercepted 16 years of data, conducted energy. The research and analysis of consumption, economic growth, and carbon emissions make the research results more accurate; the second is the scope contribution. This paper incorporates the before and after interaction into the research scope by adding a lag term, and considers the impact of nonlinear and time factors on the results; The third is the method contribution. Most domestic and foreign researchers use the auto-vector regression model (VAR), and rarely use the systematic GMM method. In this paper, the systematic GMM approach addresses the endogeneity problem well.

2. Literature review

2.1 Economic growth and carbon emission

Due to economic development, population growth and urbanization, carbon emission has gradually become a worrying global theme [2].

In the existing literature, a number of scholars have focused their research on the relationship between economic growth and carbon emission. Hanif investigated the previously unstudied Latin America and the Caribbean region, and selected data from 20 low-and-middle-income economies for the period 1990-2015. The empirical result found an "inverted U" relationship between economic growth and CO2 emission in this region, confirming the Environmental Kuznets Curve (EKC) hypothesis for developing economies in Latin America and the Caribbean [3].

2.2 Energy consumption and carbon emission

Since it' 's generally the massive use of fossil energy that plays a role in increasing carbon emission due to economic growth, many existing studies have shown that there is also a possible link between energy consumption and carbon emission.

However, regions with different levels of development vary. Among developed countries, Raza et al. used methods such as wavelet coherence spectroscopy to obtain a unidirectional causal relationship between energy consumption and carbon emission from data on the U.S. transportation sector, which exists in the short, medium, and long term [4]. However, among the BRICS and OECD developing countries, energy consumption still has a limited impact on carbon emission in the short term [5].

2.3 Literature evaluation

In the face of the increasingly serious climate situation, scholars have analyzed the linkage between carbon emission, energy consumption and economic growth in various countries from different perspectives and empirical methods. In general, economic growth tends to increase energy consumption and carbon emission, and energy consumption itself also contributes to the continuous increase in carbon emission. And specifically, there is a large heterogeneity and uniqueness between developing and developed countries, with short-term and long-term impacts. It is important to avoid "one-size-fits-all" studies for different economies.

However, the existing literature tends to stop at the national level [6], hardly achieving a detailed provincial analysis for a particular country; In contrast, this paper scientifically cleansed and rigorously studied the provincial panel data of China after overcoming multiple problems such as data availability. In addition, current studies tend to model variables such as carbon emissions in a single linear way [7], ignoring the nonlinear and time factor. Nevertheless, this paper uses dynamic methods, such as lagged terms, to take pre-post interactions into account in the study. Moreover, while traditional measurement methods usually create endogenous problems [8], this paper uses the system GMM method to solve this problem skillfully to research the relationship between economic growth, energy consumption, and carbon emission, making the study more scientific and valid.

3. Variable selection and model construction

3.1 Variable selection and data sources

3.1.1 Selection of variables

Based on the existing research literature, this paper takes the factors of energy consumption, economic growth, and carbon emissions as the core variables, and other factors as the control variables. The core variables are explained as follows:

Energy consumption (ENE): The direct linear relationship between energy consumption and carbon emissions is measured by the per capita standard coal consumption index. Economic Growth (PGDP): The productivity and wealth of the population in the region can be expressed in terms of GDP per capita. Carbon emissions (PCO2): Calculate the carbon dioxide emissions of each province using the consumption of various fossil energy through the standard coal coefficient and the carbon emission coefficient issued by IPCC. Finally, the per capita carbon emissions are calculated by dividing the total regional carbon emissions by the total population at the end of the year.

$$CO_{2it} = \sum_{x=1}^{k} (EI_{ixt} \times \sigma_x \times \rho_x) \times 44/12 \tag{1}$$

Where CO_{2it} represents the carbon emission of the year in the region, represents the coefficient of energy converted into standard coal. indicates the carbon emission factor corresponding to the energy type x.

3.1.2 Data description

All index data are from China Statistical Yearbook and China Energy Statistical Yearbook. Due to the lack of indicator data in some provinces, this paper excludes the data of Tibet and Qinghai, and uses the data of 29 provinces from 2004 to 2019 as a sample for research. Measured logarithmically on per capita emissions, economic growth, and population, Urban, TI, POP, PT, and PC represent urbanization, tertiary industry share, population, per capita trade, and per capita capital, respectively. The descriptive statistics of the original data are shown in Table 1:

Table.1. Descriptive statistics of variables

Variables	Sample size	Mean	Variance	Minimum	Maximum
ENE	464	13326.458	8292.501	742.480	41390. 000
PCO_2	464	11. 878	9.171	1.788	59.043
Urban	464	53. 718	14. 188	26.280	89.600
PGDP	464	41250.034	27485.686	4215. 000	164220. 000
TI	464	43. 445	9.540	28.600	83.500
POP	464	4597. 847	2624.295	588.000	11521. 000
PT	464	1.601	2.44	0.045	13.458
PC	464	0.190	0.339	0.004	2.669

3.2 Dynamic panel model

Considering that previous carbon emissions will affect current carbon emissions, we incorporate the carbon emissions lag term into the model, and use the two-step GMM to construct an effective and consistent estimate, using 29 provinces (cities/regions) from 2003 to 2019. In order to avoid possible endogenous interference, the difference equation and the level equation are regarded as a system of equations, and a two-step system GMM estimation is performed to improve the estimation efficiency. At the same time, the Windmeijer method was used to correct the standard deviation. The corresponding estimation is done in STATA 16.0. Model 1 takes energy consumption and economic growth as exogenous variables to explore their impact on carbon emissions, while Model 2 introduces three core variables as endogenous variables. In order to measure the impact of energy consumption and economic growth on carbon emissions, a dynamic panel model is constructed as follows:

$$lnPCO_2 = \alpha_0 + \alpha_1 lnPCO_{2_{it-1}} + \alpha_2 lnPENE + \alpha_3 lnPGDP + \alpha_4 PT + \alpha_5 TI + \alpha_6 lnPOP + \alpha_7 Urban + \mu_i + \varepsilon_{it} \tag{2}$$

In Model 1, all factors were included in the comprehensive regression analysis. Where α1 corresponds to the elasticity coefficient of the dependent variable lagging by one period, and α2, α3, α4, α5, α6 and α7 represent the regression coefficients of independent variables and controlled variables, provinces, years, time effects and random error terms, respectively.

In this paper, three core variables are introduced into the model in the form of endogenous variables. A dynamic simultaneous equation model is proposed to be estimated using the system GMM to explore the two-way relationship between energy consumption, economic growth, and carbon emissions. The model is constructed as follows:

$$lnPCO_2 = \alpha_0 + \alpha_1 lnPCO_{2_{it-1}} + \alpha_2 lnPENE + \alpha_3 lnPGDP + \alpha_4 PT + \alpha_5 TI + \alpha_6 lnPOP + \alpha_7 Urban + \alpha_8 PC + \mu_i + \varepsilon_{it} \tag{3}$$

The remaining two core variables are introduced in turn according to Model 2, which is limited in space and not presented one by one.

4. Empirical analysis

4.1 The impact of energy consumption economic growth on carbon emissions

Table 2 shows the regression results of Model 1. Columns 2 and 3 show the regression results for introducing only a single core variable and lagged carbon emissions. The economic growth coefficients estimated by Model 2 and Model 3 are -0.198 and -0.297, respectively, significantly negative. It can be considered that the improvement of the current economic level can effectively restrain the high growth of carbon emissions. As incomes rise, the emphasis on environmental protection is increasing. In Model 1 and Model 3, energy consumption also passed the 5% significance test, and the corresponding coefficient was positive, which was consistent with the expected results, indicating that energy consumption is an important driver of carbon emissions. In terms of control variables, the increase in the proportion of the tertiary industry is conducive to the upgrading of the industrial structure. It restrains the current growth of carbon emissions. Although the trade term and urbanization term are insignificant, the coefficients are positive. It shows that the development of foreign trade and urbanization may lead to an increase in production activities and thus promote an increase in carbon emissions.

Table.2. Regression results from energy consumption and economic growth in carbon emissions

Variables	Model 1	Model 2	Model 3
	Dependent variable: ln PCO_2		
ln PCO_2	0.674*** (5.21)	0.850*** (7.74)	0.462* (1.88)
ln PGDP		-0.198* (-1.89)	-0.297** (-2.06)
ln ENE	1.050** (2.27)		0.780** (2.40)
Obs	435	435	435
Control variable	YES	YES	YES
Province & year FE	YES	YES	YES
AR (2)	-0.37(0.713)	-0.45(0.653)	-0.50 (0.617)

Note: *, * * and *** are significant at the level of 10%, 5% and 1%, respectively, the same as the following table.

4.2 Empirical analysis of energy consumption, economic growth, and carbon emission

The following is a systematic GMM estimation for model 2, and regression models 4, 5, and 6 are obtained. The estimated results are shown in Table 3. Due to limited layout space, only the core coefficient variables are displayed. As can be seen from the p-value of AR (2), there is no second-order serial autocorrelation. In the carbon emission equation, the core variables of economic growth and energy consumption are significant, indicating that the increase in China's carbon emissions is largely caused by energy consumption. The estimated results are consistent with Model 3. In the energy equation, economic growth and carbon emissions positively impact energy consumption, passing the 1% significance test, indicating that economic growth and the expansion of the industrial sector can effectively promote energy production and consumption. There are no significant core variables in Model 6. Only the energy consumption coefficient is positive, indicating that the proportion of China's energy consumption driving economic growth is small, but energy consumption still has a positive impact on economic growth.

Table.3. GMM estimation results of the system

Variables	Model 4	Model 5	Model 6
	ln PCO_2	ln ENE	ln PGDP
ln PCO_2		0.455*** (3.45)	-0.030 (-0.33)
ln PGDP	-1.109** (-2.35)	0.426*** (2.48)	
ln ENE	1.563** (2.16)		0.201 (0.63)
Obs	435	435	435
Control variable	YES	YES	YES
Province & year FE	YES	YES	YES
AR (2)	0.14(0.892)	1.00 (0.320)	1.03 (0.301)

Therefore, it can be preliminarily considered that there is a two-way relationship between energy consumption and carbon emissions in the total sample, while there is a one-way relationship between economic growth and energy consumption.

4.3 Robustness test

Although the two-step SYS-GMM standard covariance matrix is always relatively robust, we use the fixed effect model to re-estimate the models 4, 5, and 6 to ensure the stability and reliability of the model, In order to reduce the impact of heteroscedasticity and autocorrelation, the clustering adjusted robust standard error is used to correct FE estimation. At the same time, considering that the carbon emission is calculated according to the carbon emission coefficient and standard coal conversion coefficient, we conducted a correlation analysis with the carbon emission result in CEADs database, and found that the correlation coefficient is as high as 0.9233, indicating that the variables are consistent and have strong objectivity. The regression results are shown in Table 4. The regression results have not changed the basic conclusions of this paper, which shows that the model is robust to some extent.

Table.4. FE regression results

Variables	Dependent variable		
	ln PCO_2	ln ENE	ln PGDP
ln PCO_2		0.434*** (8.36)	0.030 (0.39)
ln PGDP	-0.136* (-1.76)	0.148*** (2.96)	
ln ENE	1.470*** (11.87)		0.142 (0.86)
Obs	464	464	464
Control variable	YES	YES	YES
Province & year FE	YES	YES	YES
F	528.5	383.7	1533.41

4.4 Heterogeneity Analysis

To further explore whether these three relationships are different at the regional level, this paper divides the entire sample into eastern, central, and western regions for analysis. In order to avoid the estimation bias caused by the ineffectiveness of GMM in small samples, the FE model was used for regression, and the cluster robust standard error was used for correction. The results reported in Table 5 show that the relationship between energy consumption, economic growth, and carbon emissions varies across regions. It can be seen that, as far as the eastern region is concerned, economic growth can significantly reduce per capita carbon emissions, indicating that residents in the eastern area are gradually improving their requirements for environmental quality in the process of economic growth, and the economic development mode is changing. From the energy consumption situation, it can be seen that the current economic development in the east is still highly dependent on energy, and further green transformation is needed.

For the central region, per capita carbon emissions have a negative inhibitory effect on economic growth, which indicates that the target constraint of carbon emission reduction may affect local economic production activities, and the regional industrial chain urgently needs to transform into a low-carbon model. The impact of economic growth in the western region on carbon emissions is still positive, indicating that the current economic model is extensive and the awareness of environmental protection needs to be strengthened. The regression results of different regions show that there is always a two-way relationship between energy consumption and carbon emissions, with a significant positive coefficient, which means that it is necessary to optimize the energy consumption structure and improve the utilization efficiency of fossil energy. Developing alternative clean energy is the best way to realize benign interaction among them.

Table.5. Regression results in different regions

Dependent variable	Independent variable	The East Area	The Middle Area	The West Area	FE
ln PCO_2	ln ENE	1.803***	1.138***	1.446***	YES
	ln PGDP	-0.387**	-0.218	0.257	YES
ln ENE	ln PCO_2	0.303***	0.565***	0.408***	YES
	ln PGDP	0.331***	0.289***	-0.102	YES
ln PGDP	ln PCO_2	0	-0.331*	0.137	YES
	ln ENE	0.793***	0.489*	-0.188	YES

At the same time, in order to avoid estimation errors caused by different model settings when regressing in different regions, a pairwise comparison was performed in the western Middle East using Fisher's Permutation test. The results are shown in Table 6. E-W represents the test statistic of the coefficient difference between groups in the eastern region and the western region. The rest are the same. Obviously, there is no significant difference in the results, and the comparison between groups is robust.

Table.6. Pairwise comparison results between different regions

Dependent variable	Independent variable	E-W	E-M	W-M
ln PCO_2	ln PGDP	-0.644**	-0.169	0.475*
	ln ENE	0.356	0.664	0.308
ln ENE	ln PGDP	0.433***	0.042	-0.391**
	ln PCO2	-0.105	-0.262*	-0.157
ln PGDP	ln PCO2	-0.138	0.331	0.469**
	ln ENE	0.982**	0.305	-0.677*

5. Analysis conclusion

Based on the panel data of 29 provinces (cities, districts) from 2004 to 2019, this paper conducts an empirical analysis of the relationship between carbon emissions, economic growth and energy consumption. It draws the following conclusions: (1) Energy consumption will promote carbon emissions. However, the improvement of economic level and the increase of the proportion of the tertiary industry will inhibit the growth of carbon emissions. (2) There is regional heterogeneity in carbon emissions, economic growth, and energy consumption. There is a two-way relationship between energy consumption, economic growth, and carbon emissions in the central and eastern regions. In the eastern region, economic growth drives the increase in carbon emissions, while in the central region, the rise in carbon emissions will restrict the expansion of the economic scale. At the same time, there is a two-way relationship between energy consumption and carbon emissions in the western region.

6. Policy implications

(1) Optimize the energy consumption structure, reduce the proportion of fossil energy, encourage research and investment in clean energy, and improve the efficiency of energy use. A high level of economic growth can restrain the growth of carbon emissions, and it is necessary to speed up the transformation of the economic development mode to a low-carbon economic model. Promote the transformation and upgrading of the industrial structure, vigorously promote the development path of new industrialization, and encourage the industry to adopt and develop new technologies for energy conservation and emission reduction.

(2) While ensuring economic growth in the eastern region, enterprises should speed up the transformation of production methods and improve the green level. For the central region, it is a feasible path to actively introduce carbon reduction technologies and enhance environmental protection awareness. The western region should reduce energy dependence, increase investment in clean energy research and development, and transform the model of economic growth.

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