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An Empirical Study on the Impact of China's Energy Consumption on Economic Growth Under the Background of "Dual Carbon"

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Abstract: Our country is faced with a complex economic development environment at present stage, such as imbalance of global energy supply and demand. It is very important to study the energy consumption structure to our economic development. In this paper, economic growth, coal consumption, oil consumption, natural gas consumption, primary power consumption and other energy consumption during 1992-2021 are used as time series data to analyze the impact of coal consumption, oil consumption, natural gas consumption, primary power consumption and other energy consumption on China's economic growth. The empirical results show that oil consumption, primary power consumption and other energy consumption have a significant positive effect on our economic growth. Oil consumption, primary power consumption and other energy consumption can promote our economic growth, that is, every 1% increase in oil consumption, on average, GDP increases by 1.472%. When primary electricity and other energy consumption increases by every 1 percent, on average, our GDP increases by 0.419 percent. But total energy consumption, coal consumption and natural gas consumption have an insignificant effect on our economic growth. Therefore, our country actively takes measures to promote our economy to realize green economy, and then realize the "double carbon" goal as soon as possible.

Keywords: Energy Consumption, Economic Growth, Time Series Data, Cointegration Analysis, Analyze Multicollinearity

1. Introduction

The report of the 20th National Congress of the Communist Party of China points out that the main goal of China's economic development in the next five years is to achieve new breakthroughs in high-quality development, significantly enhance the autonomy of scientific and technological innovation, and make greater progress in building a new development pattern and constructing a modern economic system. Currently, China is the country with the largest energy demand in the world and is facing the imbalance of global energy supply and demand as well as difficulties in finding alternative energy sources. Therefore, it is crucial to adjust the energy consumption structure reasonably for China's economic development.

In the "Outline of the Fourteenth Five-Year Plan" of our country, it is explicitly stated that one of the main indicators of our economic development is to reduce energy consumption per unit of GDP and improve energy efficiency. Based on the background of "dual carbon", this article analyzes the impact of energy consumption on economic growth in our country and puts forward some reference suggestions.

Energy is the driving force behind China's economic development. Currently, our country's energy consumption relies mainly on the combustion of fossil fuels, namely coal, oil, and natural gas. However, the extensive burning of fossil fuels leads to serious environmental problems and resource depletion, which can hinder our country's sustainable economic development. Therefore, reducing energy consumption is a key focus for achieving economic sustainability. The promotion of the "dual carbon" target, which aims to adjust the energy structure and broaden the path of green economic development, provides empirical support for sustainable economic development.

There is an objective intrinsic connection between economic development and energy consumption. Excessive economic development inevitably leads to excessive energy consumption, which in turn results in high carbon emissions and prevents the achievement of the "dual carbon" goals. On the other hand, low energy consumption may reduce carbon emissions, but it also hinders economic development and gives rise to a series of social problems, particularly high unemployment rates and difficulties in people's lives. Finding a balance between the "dual carbon" goals and people's livelihoods is the theoretical and practical significance of this study.

2. Literature Review

The relationship between energy consumption and economic growth was first proposed by Donella Meadow, Jorgen Randers, and Dennis Meadows in 1972. They believed that energy consumption is one of the factors influencing economic growth. Taclie Evelyn Agba et al. (2022) used a series of causal relationships to demonstrate that there is a bidirectional causal relationship between energy consumption and economic growth [1]. Piłatowska Mariola and Geise Andrzej (2021) conducted research on France, Sweden, and Spain, which showed that energy consumption cannot decouple economic growth from carbon emissions. Global coordinated policy actions should be taken to transform fossil fuel economies into low-carbon economies in order to achieve the "dual carbon" goals [2].

Research on energy economics in China began in the 1980s, relatively late. Li Zhao (2022) constructed a model of the relationship between energy consumption and economic growth from the perspectives of technological progress and capital investment using the Uzawa-Lucas model [3]. Guo Yudong (2015) integrated data and used panel analysis methods such as stationary tests and entropy cointegration to analyze the relationship between energy consumption and economic growth, and the results showed that a decrease in energy consumption would lead to a decrease in GDP [4]. Ma Qianli and Fu Daishan (2018) studied the relationship between energy consumption, technological progress, and economic growth using the VAR model, and found that the relationship between energy consumption and economic growth in China exhibited a "U-shaped" pattern, and the mutual influence between energy consumption and economic growth remained stable in the long term [5]. Xu Yi (2017) constructed a VAR model and found that new energy consumption has a positive impact on economic growth [6]. Shao Shuai, Yang Lili, and Qi Zhongying (2009) introduced the energy sector as a passive explanatory factor in Romer's R&D model and established a four-sector endogenous growth model for the energy sector. They concluded that the impact of energy development on economic growth could be both promoting and hindering [7]. Qi Shaozhou, Zhang Qian, and Wang Banban (2017) believed that China is currently facing an expanding gap in government subsidies for new energy, and they regarded venture capital as an internal influencing mechanism. They also explored the impact of heterogeneous factors on the role of venture capital in new energy enterprises and found that venture capital has a significant impact on the innovation capability of new energy enterprises [8]. Lin Boqiang (2021) studied the current situation of energy consumption in China and believed that China will achieve its carbon neutrality goal mainly through clean energy [9]. Lan Mengxin (2021) pointed out that different modes of energy consumption have different economic impacts on different regions, and targeted measures must be taken to restrict energy consumption and optimize energy consumption structure [10]. Xu Limeng (2019) conducted Granger tests and impulse response function analysis on 11 EU countries and concluded that non-renewable energy promotes short-term economic growth, while renewable energy consumption has long-term promoting effects on the economy [11]. Cheng Fang (2020) believed that rapid economic growth cannot be achieved without the support of capital and energy consumption [12]. Yin Shuo, Yang Meng, and Chen Xing (2022) found that there is a long-term equilibrium relationship between industrial optimization and energy consumption, and they have a causal relationship that is bidirectional [13]. Liu Yongqi, Chen Longxiang, and Han Xiaoqi (2022) studied the key issues of new energy substitution under energy transition in China [14]. Li Qian, Zhao Yanyun, and Liu Bingjie (2021) quantitatively analyzed the policies of the new energy industry and the environmental effects generated [15].

Scholars both domestically and internationally have conducted valuable research on energy consumption and economic growth, achieving different results. These findings serve as the foundation for further research. However, there is a lack of research on the impact of China's energy consumption on economic growth using a 30-year time series data. Therefore, studying this topic holds both theoretical and practical significance.

3. The Current Situation of Energy Consumption and Economic Growth in China

3.1. The Current Situation of Energy Consumption in China

3.1.1. Analysis of China's Energy Supply and Demand Situation and Gap

China is a large energy-consuming country and also a major energy importer. The basic situation of China's energy resources is rich in coal, poor in oil, and scarce in natural gas. The domestically produced coal can be self-sufficient, while the oil and natural gas mainly rely on imports. In recent years, under the impact of the pandemic, the exploration and improvement of energy consumption in China have continued to increase. Compared with other countries, China's energy is not balanced, and its economic development is limited by a single energy source. In the context of sustainable economic development, energy consumption, as an important part of economic development, can provide development impetus for China's sustainable economic development while ensuring sufficient energy supply and guaranteeing the material supply and communication of residents' lives and industrial production. However, in recent years, due to the constraints of energy supply, China's energy supply-demand gap has been increasing. This article selects the data of China's energy supply-demand gap from 1992 to 2021 to explore the current situation of China's energy.

As shown in Table 1, there has been a long-term positive growth trend in China's energy supply and demand from 1992 to 2021. In 1992, the energy supply-demand gap was only 19.14 million tons of standard coal, but by 2021, this gap had reached 91,000 million tons of standard coal, indicating a rapid expansion of the gap. Among them, the largest energy supply-demand gap is in the petroleum sector, which has shifted from oversupply in 1992 to undersupply in 2021, with a gap of 68,362 million tons of standard coal. The natural gas and coal sectors also have significant supply-demand gaps. In 1992, the natural gas supply and demand were balanced, but by 2021, the natural gas gap reached 20,223 million tons of standard coal. The coal supply-demand gap was 2,950 million tons of standard coal in 1992, and it increased to 3,330 million tons of standard coal in 2021. China has a relatively small gap in electricity and other energy supply and demand, but the proportion of electricity and other energy consumption to total energy consumption is relatively low, remaining at around 16% as of 2021. China relies heavily on imported energy to meet domestic energy demand.

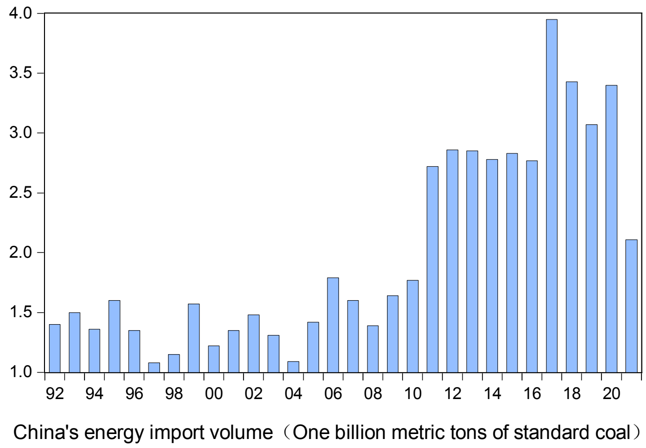


Figure 1. *China's energy imports from 1992 to 2021.*

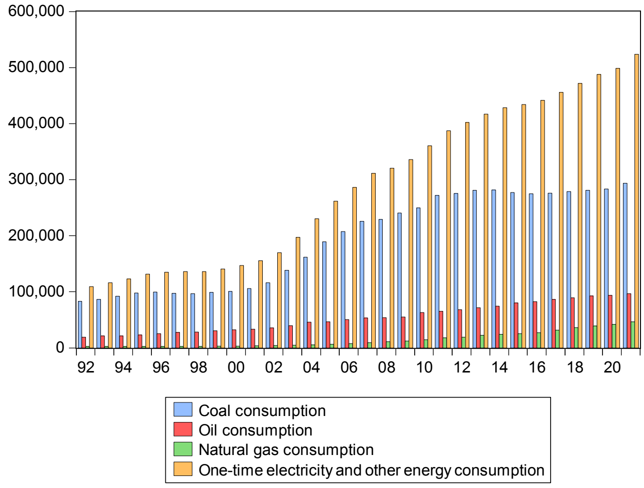
Data sources: United Nations "Energy Statistics Yearbook", National Bureau of Statistics, General Administration of Customs.

From Figure 1, China's comprehensive energy imports have shown an overall upward trend. The import volume has increased from 1.4 billion metric tons of standard coal in 1992 to 3.4 billion metric tons of standard coal in 2020. The quantity has increased by more than 1.43 times compared to 1992 in 2020.

However, the growth rate has shown a fluctuating downward trend. According to statistics from the General Administration of Customs, China's net energy imports reached a total of 1.12 billion tons of standard coal in 2021, with net coal imports reaching a new high of 320 million tons. Crude oil net imports have remained at a high level since surpassing 500 million tons in 2019, reaching 510 million tons in 2021. In addition, natural gas net imports have grown rapidly, reaching 16.2 billion cubic meters in 2021. It can be seen that China's energy dependence on foreign countries continues to increase, but due to the significant increase in energy consumption, the energy supply is insufficient and the energy supply-demand gap continues to widen. China's energy security urgently needs to be addressed.

3.1.2. Changes in China's Energy Consumption Structure

The total energy consumption is composed of coal, oil, natural gas, and primary electricity consumption, along with other forms. Studying the scientific and rational nature of China's energy consumption structure is an important basis for achieving sustainable economic development. The changes in energy consumption structure will also transform China's economic development mode. This article selects the consumption volume and proportion of coal, oil, natural gas, and primary electricity in China from 1992 to 2021 to study the evolution of China's energy consumption structure.



Data source: National Bureau of Statistics.

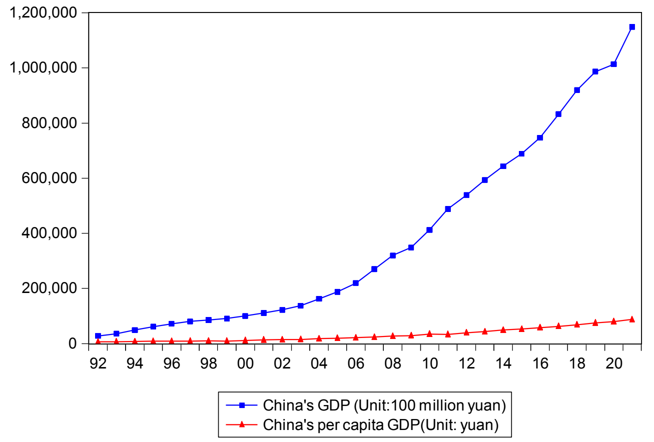
Figure 2. *Energy consumption structure in China from 1992 to 2021.*

According to Figure 2, it can be seen that there has been little change in China's energy consumption structure. Coal consumption accounts for the majority of the total energy consumption. Before 2000, coal consumption remained stable. After 2000, coal consumption showed an overall upward trend, gradually widening the gap with oil, natural gas, primary electricity, and other energy consumption. However, the total energy consumption showed an increasing trend, with an accelerated consumption rate. However, in 2016, the growth rate of China's energy consumption began to decline, mainly due to the end of the high-speed development period of China's economy during the "12th Five-Year Plan" period, which brought about new changes in the energy consumption structure due to the new normal of China's economic growth rate. In particular, the relatively small increase in energy consumption from 2016 to 2021 for four consecutive years indicates that China's total energy consumption is gradually reaching its peak. In addition, the "Dual Carbon" target was proposed in 2020, which has had an impact on China's energy consumption structure.

3.2. The Current Situation of Economic Growth in China

3.2.1. Analysis of the Current Situation of China's Economic Growth in Terms of Total Volume and Per Capita Level

Economic development represents the process of a country or region's actual welfare growth per capita, while economic growth indicates the overall growth rate of a country or region's economic strength. Since the reform and opening-up policy, China has achieved significant accomplishments in its economy, becoming the world's second-largest economy, which is sufficient to demonstrate its overall economic strength. This article extracts the total economic growth and per capita level of China from 1992 to 2021, analyzing the trend of China's economic growth.



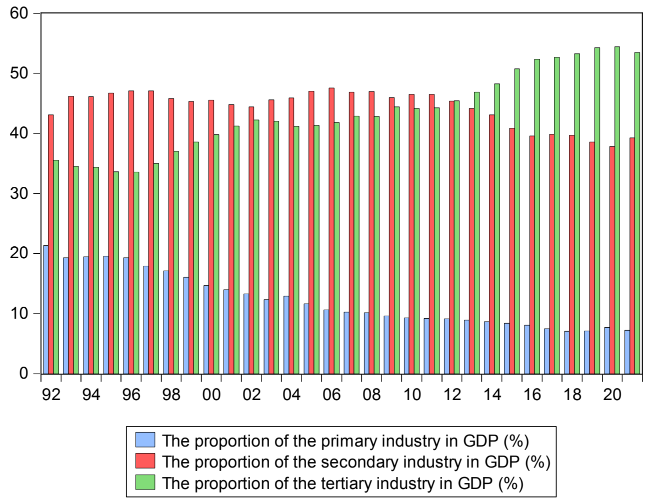
Data source: National Bureau of Statistics.

Figure 3. *The total amount and per capita level of economic growth in China from 1992 to 2021.*

According to Figure 3, China's economic growth and per capita level have shown a continuous upward trend from 1992 to 2021. According to the data from the National Bureau of Statistics in 2021, China's GDP reached 114,923.7 billion yuan, an increase of 13.4% compared to 2020 and an increase of 41.3% compared to 1992. In terms of per capita level, China's per capita GDP reached 81,370 yuan in 2021, an increase of 13.3% compared to 2020 and an increase of 33.9% compared to 1992. It can be seen that in these years, under the epidemic, China has adhered to sustainable economic development, maintained the trend of economic growth during the epidemic, and achieved good results. In conclusion, considering the analysis of domestic and international environments, China's economy will not change its trend of sustained growth. With the emergence of new concepts such as "green GDP" in sustainable economic development and related green and low-carbon industries, combined with the progress of science and technology in China, the trend of China's economic growth will continue to strengthen.

3.2.2. Trends in China's Industrial Structure Change

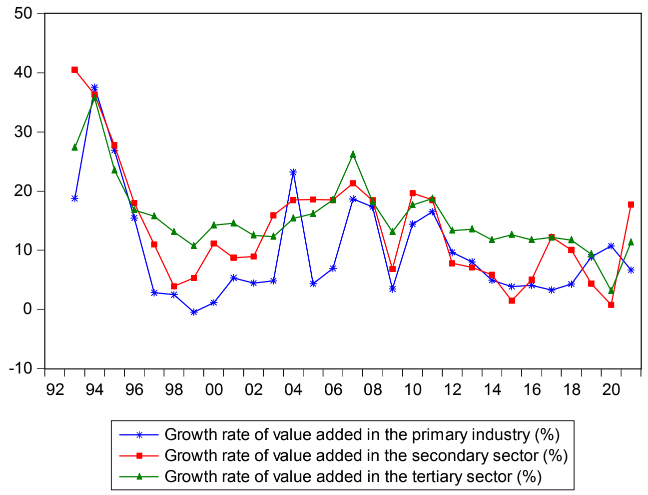
The economic development of a society encompasses three aspects: the growth of economic quantity, the improvement of economic structure, and the enhancement of quality of life. The most important component of economic structure is industrial structure. The sum of the output value of the primary industry, the secondary industry, and the tertiary industry constitutes the Gross Domestic Product (GDP) of our country. Studying whether our country's industrial structure is scientifically reasonable can serve as an important reference for policy-making and promote the achievement of sustainable economic development. Therefore, it is necessary to study the industrial structure for economic development. This article selects the output value and proportion of the primary industry, the secondary industry, and the tertiary industry in China from 1992 to 2021 to study the evolution and process of China's industrial structure.



Data source: National Bureau of Statistics.

Figure 4. *The proportion of China's three industries in the country's gross domestic product (GDP) from 1992 to 2021.*

According to Figure 4, it can be seen that the three industries in China have maintained long-term positive growth in line with the overall economic size. Over the 30-year period from 1992 to 2021, the value of the first industry in China increased from 580.03 billion yuan to 8,321.65 billion yuan, with a year-on-year growth rate of 6.65%; the value of the second industry increased from 1,172.5 billion yuan to 45,154.41 billion yuan, with a year-on-year growth rate of 17.72%; and the value of the third industry increased from 966.92 billion yuan to 61,447.64 billion yuan, with a year-on-year growth rate of 11.32%. In terms of the proportion of the three industries in China's GDP, the proportion of the first and second industries has generally decreased, while the proportion of the third industry has generally increased. This trend is in line with the theory of sustainable economic development.



Data source: National Bureau of Statistics.

Figure 5. *The changes in the three industries in China from 1992 to 2021.*

In Figure 5, the growth rates of the three industries in China from 1992 to 2021 showed a fluctuating downward trend. In 2020, the year when the COVID-19 pandemic hit, the year-on-year growth rate of the primary industry in China accelerated, but the year-on-year growth rate of the secondary industry was only 0.76%, and the year-on-year growth rate of the tertiary industry was only 3.14%. The main reason was that both the secondary and tertiary industries were severely impacted by the pandemic, and China was in a critical period of epidemic prevention and control, which made it difficult for these industries to resume production and operation, resulting in operational difficulties and affecting the country's economic development. However, in 2021, China gradually implemented the "dynamic zero tolerance" policy, making adjustments and focusing on promoting the normal operation of the secondary and tertiary industries to restore the national economy. Therefore, the year-on-year growth rates of the three industries in China in 2021 gradually returned to the pre-pandemic state.

4. Empirical Research on the Impact of Energy Consumption on Economic Growth in China

4.1. Variable Selection

After reviewing a large number of literature, it was found that there is a lack of research on the impact of different components of energy consumption on economic growth, despite the abundance of studies on the overall impact of energy on economic growth. Moreover, the existing research on this topic has a relatively short time span. Therefore, this study collected annual data on economic growth, coal consumption, oil consumption, natural gas consumption, and primary electricity and other energy consumption for the years 1992-2021, spanning a total of 30 years. The economic growth of China was chosen as the dependent variable, while the different components of energy consumption were selected as the independent variables. In order to ensure comparability and reduce the occurrence of heteroscedasticity, all data were transformed into logarithmic form for comprehensive analysis.

4.2. Descriptive Statistics of Variables

From 1992 to 2021, the time series data in China shows that energy consumption has been on the rise, closely following the growth of GDP. In order to facilitate the analysis of the impact of various components of energy consumption on economic growth, this study uses Eviews 10 software to calculate the average, median, maximum, minimum, and standard deviation of the logarithms of economic growth (LNGDP), coal consumption (LNCC), oil consumption (LNOC), natural gas consumption (LNGC), and primary electricity and other energy consumption (LNPC), as shown in Table 1.

Table 1. *Descriptive Statistics of Explanatory and Dependent Variables.*

Variable	LNGDP	LNCC	LNOC	LNGC	LNPC
mean value	12.35323	12.06653	10.7663	9.058056	10.00062
median	12.40267	12.2849	10.84971	9.047947	10.0102
maximum value	13.95461	12.58943	11.48185	10.75013	11.37348
minimum value	10.21079	11.32227	9.857705	7.637234	8.584665
Standard deviation	1.107105	0.48255	0.514574	1.077465	0.866334
skewness	-0.193245	-0.316849	-0.231647	0.102405	-0.003847
Kurtosis	1.816747	1.336153	1.742172	1.501406	1.694345
P-value	0.379685	0.1379	0.325308	0.239349	0.344557
Sample size	30	30	30	30	30

4.3. Empirical Analysis

4.3.1. Unit Root Test

In order to prevent the occurrence of "spurious regression" due to non-stationarity in time series data and ensure the scientific validity of the test results, it is necessary to conduct stationarity tests on all explanatory variables and the dependent variable. This study uses the ADF unit root test method to test the stationarity of variables, and the test results are shown in Table 2.

Table 2. *Results of ADF Unit Root Test.*

Testing variables	Type verification (C, T, K)	ADF statistic	Critical values of ADF at a significant level 1%	5%	10%	D.W value	P-value	Test results
LNGDP	(C, T,3)	-1.957	-4.356	-3.595	-3.233	1.749	0.597	unstable
D(LNGDP)	(C,0,0)	-2.775	-3.689	-2.972	-2.625	1.709	0.075	unstable
D(LNGDP,2)	(0,0,1)	-4.500	-2.657	-1.954	-1.609	1.720	0.0001	stable ***
LNCC	(C, T,1)	-2.373	-4.324	-3.588	-3.225	2.306	0.3845	unstable
D(LNCC)	(C,0,2)	-2.647	-3.711	-2.981	-2.630	1.697	0.0968	unstable
D(LNCC,2)	(0,0,2)	-3.527	-2.661	-1.955	-1.609	1.945	0.0011	stable ***
LNOC	(C,0,0)	-1.966	-3.679	-2.968	-2.623	2.262	0.2991	unstable
D(LNOC)	(C, T,0)	-5.904	-4.324	-3.581	-3.225	1.880	0.0002	stable ***
D(LNOC,2)	(C,0,1)	-6.683	-2.657	-1.954	-1.609	2.326	0.0000	stable ***
LNGC	(C, T,7)	-5.037	-4.441	-3.633	-3.255	2.369	0.0029	stable ***
D(LNGC)	(C,0,0)	-2.950	-3.689	-2.972	-2.625	2.018	0.0524	unstable
D(LNGC,2)	(0,0,1)	-5.598	-2.657	-1.954	-1.609	2.132	0.0000	stable ***
LNPC	(C,0,0)	-3.040	-4.310	-3.574	-3.222	1.901	0.1394	unstable
D(LNPC)	(C, T,2)	-4.086	-4.356	-3.595	-3.233	1.940	0.0180	stable **
D(LNPC,2)	(0,0,3)	-3.867	-2.665	-1.956	-1.609	2.059	0.0005	stable ***

Note: (C, T, K) represents the type of test, where C indicates the presence of a constant term in the test, T indicates the presence of a time trend term in the test, and K represents the lag order. D(LN*) represents first-order difference, and D(LN*,2) represents second-order difference. *** indicates rejection of the null hypothesis of non-stationarity at the 1% significance level, while ** indicates rejection at the 5% significance level.

According to Table 2, it can be seen that the original sequences LNGDP, LNCC, LNOC, and LNPC are all non-stationary. The first-order difference sequences D(LNGDP), D(LNCC), and D(LNGC) are also non-stationary. However, the second-order difference sequences D(LNGDP,2), D(LNCC,2), D(LNOC,2), D(LNGC,2), and D(LNPC,2) exhibit stationarity at the 1% or 5% significance level, indicating that they follow an I(2) process. This suggests that under the condition of second-order differencing, the variable data becomes stationary, indicating that the sequences are of the same order of integration and satisfy the conditions for cointegration analysis. Therefore, the model can be specified as:

$$LNGDP = \beta_0+\beta_1 LNCC +\beta_2 LNOC+\beta_3 LNGC+ \beta_4 LNPC+\varepsilon t \quad (1)$$

Among them, LNGDP represents the logarithm of economic growth, LNCC represents the logarithm of coal consumption, LNOC represents the logarithm of oil consumption, LNGC represents the logarithm of natural gas consumption, LNPC represents the logarithm of primary electricity and other energy consumption, and εt represents the random disturbance term.

Due to the rejection of the null hypothesis of stationarity at the 1% or 5% significance level for the second-order difference sequences D(LNGDP,2), D(LNCC,2), D(LNOC,2), D(LNGC,2), and D(LNPC,2), they are considered to be integrated of the same order. Therefore, they meet the prerequisite for conducting cointegration tests. Consequently, this study will further conduct cointegration tests under the condition of second-order differencing.

4.3.2. Cointegration Test

According to the results of the ADF unit root test, it can be inferred that the five variables are integrated of the same order, indicating the possibility of cointegration. Therefore, a cointegration test can be conducted. In this study, the Engle-Granger two-step method is selected, and the Eviews 10 software is used to perform the cointegration test.

First, the equation is estimated using Ordinary Least Squares (OLS) for model (1). Then, residuals are obtained based on the equation. Finally, the residuals are subjected to the Augmented Dickey-Fuller (ADF) unit root test, and the results are shown in Table.

Table 3. *ADF unit root test for residuals.*

Testing variables	Type verification (C, T, K)	ADF statistic	Critical values of ADF at a significant level 1%	5%	10%	D.W value	P-value	Test results
e	(0,0,0)	-3.034	-2.647	-1.953	-1.610	1.563	0.0037	stable***

Note: (C, T, K) represents the type of test, where C indicates whether there is a constant term in the test, T indicates whether there is a time trend in the test, and K represents the lag order. *** indicates rejection of the null hypothesis of non-stationarity at the 1% significance level.

According to Table 3, the p-value of the ADF test for the residuals (e) is 0.0037, which indicates that the p-value of the residuals (e) rejects the null hypothesis at a significance level of 1%. Through the significance test, it can be concluded that there is a cointegration relationship between the variables. Based on the cointegration test, the basic equation can be obtained from Table 4, as shown in equation (2).

$$\begin{matrix} LNGDP \\ T \end{matrix} = \begin{matrix} 0.057910 * LNCC \\ (0.302018) \end{matrix} + \begin{matrix} 1.239466 * LNOC \\ (3.083833) \end{matrix} - \begin{matrix} 0.029084 * LNGC \\ (-0.162330) \end{matrix} + \begin{matrix} 0.543341 * LNPC \\ (1.654338) \end{matrix} - \begin{matrix} 6.860308 \\ (-4.214951) \end{matrix} \quad (2)$$

R^2 = 0.991, DW = 0.51, F = 734.83, N = 30.

4.3.3. Testing and Correction for Multicollinearity

The p-values corresponding to the T-statistic of LNOC are all less than 5%, indicating rejection of the null hypothesis at a significance level of 5% and passing the significance test. However, the p-values of the T-tests for LNCC, LNGC, and LNPC are all greater than 5%, suggesting the possibility of multicollinearity in the model.

To address the issue of multicollinearity in the model, this article proposes using stepwise regression method in Eviews 10 for correction. Firstly, a simple regression is performed for each explanatory variable with the dependent variable, and the importance of each explanatory variable is determined based on R^2. The explanatory variables are then sorted, and separate univariate regression models are constructed for LNCC, LNOC, LNGC, and LNPC, as shown in Table 4.

Table 4. *Results of the Univariate Regression (Dependent Variable: LNGDP).*

Variable	LNCC	LNOC	LNGC	LNPC
Estimated parameter value	2.209740	2.139851	1.011052	1.268767
T statistic	18.94916	50.64913	29.20916	43.97442
R^2	0.927662	0.989203	0.968224	0.985727

The regression results show that the regression equation of LNGDP and LNCC has an R^2 of 0.927662, the regression equation of LNGDP and LNOC has an R^2 of 0.989203, the regression equation of LNGDP and LNGC has an R^2 of 0.968224, and the regression equation of LNGDP and LNPC has an R^2 of 0.985727. Among them, the regression equation of LNGDP and LNOC has the highest R^2, indicating that oil has the greatest impact on economic growth. Therefore, the explanatory variable LNOC and the dependent variable LNGDP are used as the basis for the regression equation, i e., LNGDP = -10.68505 + 2.139851*LNOC. LNPC, LNGC and LNCC are then introduced step by step. The results are shown in Table 5.

Table 5. *Regression Results with Introduction of New Variables (Dependent Variable: LNGDP).*

Variable	LNOC	LNPC	LNGC	LNCC	Adjusted R^2
LNOC, LNPC	1.313821 (4.304365)	0.494501 (2.7275481)			0.990908
LNOC, LNGC	1.721188 (8.000732)		0.203530 (1.981005)		0.989875
LNOC, LNCC	2.144594 (12.40575)			-0.005222 (-0.028329)	0.988404

By comparing the three regression models in Table 5, it can be concluded that the economic significance of the LNCC regression coefficient is unreasonable, while the economic significance of the LNPC and LNGC regression coefficients is reasonable. Moreover, when introducing the variables LNPC into the regression equation with the variables LNGDP and LNOC, the adjusted R^2 value increases from 0.988817 to 0.990908, and the t-test is significant. Similarly, when introducing the variable LNGC into the regression equation with the variables LNGDP and LNOC, the adjusted R^2 value increases from 0.988817 to 0.989875. However, the adjusted R^2 value is highest in the regression equation with the variable LNPC, indicating a better fit. Therefore, the explanatory variables LNOC and LNPC are used as the basis for the regression equation with the dependent variable LNGDP, and other explanatory variables are introduced accordingly. This is shown in Table 6.

Table 6. *Regression Results with Introduction of New Variables (Dependent Variable: LNGDP).*

Variable	LNOC	LNPC	LNGC	LNCC	Adjusted R^2
LNOC, LNPC, LNCC	1.265425 (3.497858)	0.499759 (2.692594)		0.043615 (0.261002)	0.990583
LNOC, LNPC, LNGC	1.312352 (4.156439)	0.500592 (1.719406)	-0.004232 (-0.027066)		0.990559

Based on the observation of Table 6, it can be seen that when introducing the variable LNCC into the regression equation with LNGDP and LNOC, the adjusted R^2 value is 0.990583, which is smaller than the adjusted R^2 value without the variable LNCC. This indicates a worse fit. On the other hand, when introducing the variable LNGC into the regression equation with LNGDP and LNOC, the adjusted R^2 value is 0.990559, which is smaller than the adjusted R^2 value without the variable LNGC. Moreover, this leads to the P-value of the variable LNPC being greater than 0.05, indicating that it is not significant at the 5% level and the parameter signs are not consistent. Based on the stepwise regression analysis, it can be concluded that there is multicollinearity in the model, and therefore, the variables LNCC and LNGC should be removed. Hence, the regression model with LNOC and LNPC as explanatory variables is the ideal result. By conducting the regression analysis using Eviews 10, the results after eliminating multicollinearity can be obtained.

$$\frac{LNGDP}{T} = \frac{-6.737081}{(-4.4779)} + \frac{1.313821 * LNOC}{(4.3044)} + \frac{0.494501 * LNPC}{(2.7276)} \quad (3)$$

$R^2 = 0.9915$, DW= 0.5174, F = 1581.387, N=30.

According to equation (3), the result shows that $R^2 = 0.9915$, indicating a good fit. The t-test result also shows that the impact of LNOC and LNPC on GDP is significant.

4.3.4. Autocorrelation Test and Correction for Sequences

According to the Durbin-Watson statistic, the value of 0. 5174 is close to 0, indicating that the model may have positive first-order autocorrelation. Using the LM test, it is found that the p-values of Obs*R-squared for the first to ninth orders are all less than 0.05. At a significance level of 5%, the null hypothesis is rejected. However, for the tenth order, the p-value of Obs*R-squared is greater than 0.05. At a significance level of 5%, the null hypothesis is accepted. Therefore, there is a maximum of ninth-order autocorrelation in model (3).

After confirming the existence of autocorrelation in the sequence, the model (3) was estimated using the Generalized Least Squares (GLS) method in Eviews 10, by incorporating random disturbances AR(1), AR(2),..., AR(p) to correct for the autocorrelation in the sequence. The correction results show that when adding random disturbances AR(1), AR(2),..., AR(8) to the original model, only AR(1), AR(3), and AR(8) are significant at the 5% significance level. Additionally, the Durbin-Watson (D. W) statistic is 2.255, indicating that after multiple iterations of GLS, the model no longer exhibits serial correlation. Therefore, the best regression result can be obtained as follows:

$$\frac{LNGDP}{T} = \frac{-7.68507}{(-7.5666)} + \frac{1.47163 * LNOC}{(6.4131)} + \frac{0.41906 * LNPC}{(2.7985)} + \frac{0.67535AR(1)}{(3.5423)} - \frac{0.39012AR(3)}{(-2.3869)} - \frac{0.40145AR(8)}{(2.5761)} \quad (4)$$

$R^2 = 0.99743$, DW = 2.25467, F = 1487.692, N = 30.

5. Conclusion and Policy Recommendations

5.1. Main Conclusions

According to model (4), the following conclusions can be drawn:

(1) The impact of coal consumption and natural gas consumption on economic growth is not significant.

(2) The impact of oil consumption and primary electricity and other energy consumption on economic growth is significant. Specifically, when oil consumption increases by 1%, China's GDP increases by 1.472%; when primary electricity and other energy consumption increase by 1%, China's GDP increases by 0.419%.

(3) Due to the presence of AR(1), AR(3) and AR(8), the impact of oil consumption and primary electricity and other energy consumption on economic behavior is long-lasting, with the longest significant impact lasting up to 8 years.

5.2. Policy Recommendations

5.2.1. Continuously Optimize Energy Consumption for Low-Carbon Transformation and Pursue a Green Economy

The continuous increase in oil consumption and primary electricity and other energy consumption in our country warns us to accelerate the pace of revolution in oil consumption and primary electricity and other energy consumption, speed up the transformation of oil consumption and primary electricity and other energy consumption, focus on reducing oil consumption and primary electricity and other energy consumption through substitution, reduce oil consumption and energy consumption, and at the same time accelerate the efficient and scientific use of natural gas consumption in key areas nationwide, vigorously develop non-fossil energy, thereby promoting the optimization of our country's energy consumption structure, promoting energy green and low-carbon transformation, and achieving sustainable economic development.

5.2.2. Increase Investment in Technology and Promote Energy-Saving and Carbon Reduction Projects

The impact of energy consumption on economic growth is long-lasting, but it is difficult to reduce energy consumption. Therefore, in order to achieve the "dual carbon goals," China should increase investment in science and technology to enhance its independent innovation capabilities and develop "carbon capture, utilization, and storage" technologies. This can reduce carbon emissions and mitigate global greenhouse effects. At the same time, the government should implement budget management in oil, primary electricity, and other energy consumption, strengthen energy-saving inspections for fixed asset investment projects, and comprehensively evaluate energy consumption and carbon emissions in the oil, primary electricity, and other energy sectors. By combining energy-saving and carbon reduction projects with infrastructure energy-saving upgrades, the efficiency of oil, primary electricity, and other energy resource utilization can be improved. This will promote energy-saving and carbon reduction transformations in industries such as oil and electricity, achieve green and low-carbon economic development, and further promote the realization of a green and sustainable economy in China.

5.2.3. Pursuing Moderate Growth of GDP

Excessive economic growth leads to excessive energy consumption, as indicated by model (4). For every 1.472% increase in GDP, oil consumption increases by 1%. For every 0.419% increase in GDP, primary electricity and other energy consumption increases by 1%. It is not possible for excessive economic growth rates to reduce energy consumption. Moderate economic growth is necessary to reduce energy consumption.

5.2.4. Continuously Striving to Achieve Carbon Reduction Goals

Due to the existence of the AR series, the impact of oil consumption, primary electricity, and other energy consumption on economic behavior in China is long-lasting, with the longest significant impact reaching 8 years. Therefore, whether it is in transforming the energy consumption structure, improving energy utilization efficiency, or developing new technologies for energy conservation and emission reduction, China should continue to make continuous efforts in order to achieve the "dual carbon" goal.

Fund Project

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Conflicts of Interest

The authors declare that they have no competing interests.

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