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Gray Correlation Analysis of Energy Consumption, Energy Structure and Economic Growth in China

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Abstract: Energy is not only the driving force of economic activities, but also an indispensable resource for social development and civilization, and plays a pivotal role in the national economy. However, as energy consumption continues to rise, environmental protection issues are becoming more and more prominent, and have become a common challenge faced by the world. In this paper, the data of China's gross domestic product (GDP), the consumption of each energy species and the energy consumption of each industry from 2011 to 2021 are selected for correlation analysis, and the gray correlation between various types of energy consumption and the development of the national economy is measured. Based on the above analysis, this paper finally puts forward a series of targeted policy recommendations, which are aimed at balancing the relationship between economic growth and environmental protection, promoting the green transformation of the energy industry, optimizing the energy structure, and reducing carbon emissions, so as to promote the realization of sustainable development.

Keywords: Gray correlation, Energy consumption, Energy structure, Economic growth.

1. Introduction

Energy, as an important resource, is of great significance to China's economic and social development. On the one hand, energy is the key to the country's economic development; on the other hand, energy is an indispensable material basis for social production and people's lives. In recent years, with the global response to climate change and fossil energy constraints, actively promoting energy conservation and carbon reduction and seeking energy transformation have become new development themes. Energy consumption is a "double-edged sword" closely related to economic growth, this paper intends to study the intrinsic connection between energy consumption and economic growth based on grey system theory from the perspectives of energy consumption type structure and industrial structure, which is of great scientific significance and application value for the relevant departments to save energy and reduce emissions, optimize the energy consumption structure and promote the sustainable development of the national economy. important scientific significance and application value.

2. Characteristics of Energy Consumption in China

First of all, from the industrial structure of energy consumption, China's total energy consumption in 2021 will be 5,258,960,000 tons of standard coal, of which agriculture, forestry, animal husbandry, fishery and water conservancy is the smallest industry in terms of energy consumption, with a consumption of 96,610,000 tons of standard coal, accounting for only 2% of the total consumption, while the industry is the industry with the largest energy consumption, with 348,551,000 tons of standard coal, accounting for 66% of the total consumption. 66% of the total consumption, the construction industry and agriculture, forestry, animal husbandry, fishery, water conservancy industry consumption is similar, also accounted for 2% of the total consumption, transportation, warehousing and postal industry accounted for 8% of the total consumption, wholesale and retail trade and accommodation, catering industry 148.98 million tons of standard coal, accounting for 3% of the total consumption, living energy consumption accounted for 13% of the total consumption, other tertiary energy consumption accounted for 6% of the total consumption. On the whole, the industrial sector in China is the industrial sector that consumes the most energy in China.

Secondly, from the structure of energy consumption varieties research. 2021, China's total energy consumption of 5,258,960,000 tons of standard coal, of which coal consumption is the most of all energy varieties, a total of 293,975,686,000 tons of standard coal, accounting for 55.9% of the total consumption; petroleum consumption is second only to coal, a total of 97,816,666,000 tons of standard coal, accounting for total consumption of 18.6%; natural gas consumption is lower at 462,788,500 tons of standard coal, accounting for 8.8% of the total consumption; hydropower, nuclear power and wind power consumption of 878,246,300 tons of standard coal accounts for 16.7% of the total consumption. According to the collection of 2011-2021 China's energy consumption of various types of mapping (see Figure 1), according to the data show that since 2011 coal consumption is gradually decreasing, oil consumption has increased but the overall tendency is stabilizing; natural gas consumption, hydropower, nuclear power, wind power, the proportion of the consumption of electricity since 2011 are relatively obvious upward trend, can be predicted in the near future It can be predicted that in the near future, hydropower, nuclear power and wind power will catch up with oil.

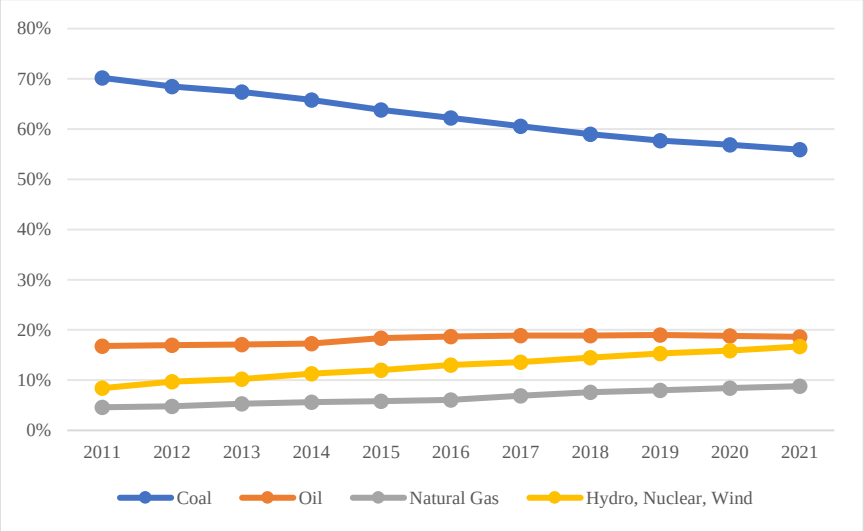

Figure 1. Trends in China's consumption of various types of energy

3. Constructing a Gray Correlation Model

Mr. Deng Julong, a professor of Huazhong University of Science and Technology, founded the gray system theory in 1982. Gray correlation analysis method does not need to consider the number of sample size and the law of sample change, not to mention that the quantitative results do not match with the qualitative analysis results, it has significant advantages in the study of small samples, poor information time series. The idea of gray correlation analysis is: according to the degree of similarity between the geometry of the parent series of the response system and the curve of the sub-series to identify the degree of correlation between the parent series and the sub-series, and quantify the relationship between the variables through the way of thinking of the correlation coefficient, the larger the correlation coefficient, the greater the degree of correlation [2]. Gray correlation analysis is now used to construct the gray correlation model process is as follows:

Step 1: The dependent variable reference series x_0 and the independent variable comparison series $x_i(k)$ are selected in the original series.

$$x_0(k) = (x_0(1), x_0(2), \ldots\ldots, x_0(k))$$

$$x_i(k) = (x_i(1), x_i(2), \ldots\ldots, x_i(k))$$

Step 2: Take the reference series, the comparison series using the initial value method and take the dimensionless treatment with the following formula:

$$x_0(k) = (\frac{x_0(1)}{x_0(1)}, \frac{x_0(2)}{x_0(1)}, \ldots, \frac{x_0(k)}{x_0(1)})$$

$$x_i(k) = (\frac{x_i(1)}{x_i(1)}, \frac{x_i(2)}{x_i(1)}, \ldots, \frac{x_i(k)}{x_i(1)})$$

Step 3: The gray correlation coefficients of the reference and comparison sequences are calculated with the following formula:

$$\gamma_{(k)} = \frac{min|x_0(k) - x_i(k)| + \xi max|x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \xi max|x_0(k) - x_i(k)|}$$

Where "A" is the resolution factor, which usually takes the value of 0.5, $\xi \in (0, 1)$.

Step 4: Calculate the gray correlation P. The value of P is the average of multiple gray correlation coefficient values of the compared sequences with the following formula:

$$P = \frac{\sum \Upsilon_i(k)}{n}$$

4. Gray Correlation Analysis of China's Economic Growth and Industrial Structure of Energy Consumption

4.1. Selection of Relevant Data

In this paper, energy consumption and gross domestic product (GDP) data from 2011 to 2021 in the statistical yearbook are organized, and a model is established on this basis to calculate the correlation between the structure of energy varieties and industrial structure and economic growth, respectively, with energy consumption of each industry represented by x_i in tons of standard coal, and GDP represented by GDP in billions of yuan. The energy consumption of agriculture, forestry, animal husbandry, fishery and water conservancy is denoted by x_1, the energy consumption of industry is denoted by x_2, the energy consumption of construction is denoted by x_3, the energy consumption of transportation, warehousing and postal services is denoted by x_4, the energy consumption of wholesale and retail trade, accommodation and catering is denoted by x_5, and the energy consumption of domestic energy consumption is denoted by x_6. According to the previous explanation, the gray correlation of the selected factors is relative, and the correlation coefficients and correlation degrees calculated at last are the correlation coefficients and correlation degrees between the total energy consumption of the six types of industries and the GDP, and the specific data are shown in Table 1.

Table 1. Data on the industrial structure of GDP and energy consumption

Year	GDP (Billions)	Energy consumption by sector (tons of standard coal)					
		x_1	x_2	x_3	x_4	x_5	x_6
2021	1149237.00	9661.00	348551.00	9608.00	43935.00	7795.38	67481.00
2020	1013567.00	9263.00	332625.00	9320.00	41309.00	8545.86	64380.00
2019	986515.20	9018.00	322503.00	9142.00	43909.00	10598.16	61709.00
2018	919281.10	8781.00	311151.00	8685.00	43617.00	10873.01	60436.00
2017	832035.90	8931.23	294488.04	8554.51	42190.79	11403.69	57620.31
2016	746395.10	8544.06	290255.00	7990.93	39651.21	12012.23	54208.66
2015	688858.20	8231.66	292275.96	7696.41	38317.66	12475.43	50098.96
2014	643563.10	8094.27	295686.44	7519.58	36336.43	12994.00	47212.33
2013	592963.20	8054.80	291130.63	7016.97	34819.02	13624.00	45530.84
2012	538580.00	6784.43	252462.78	6167.37	31524.71	13171.00	39666.09
2011	487940.20	6758.56	246440.96	5872.16	28535.50	14898.00	37409.94

4.2. Raw Data Deprogramming

Taking the 2021 data as the reference series the raw data of energy consumption of each industry collated from the statistical yearbook were processed without dimension, and each data was standardized into the data between 0-1, and the processed data is shown in Table 2.

Table 2. Data dimensionless results

	2021	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011
GDP	1.00	0.88	0.86	0.80	0.72	0.65	0.60	0.56	0.52	0.47	0.42
x_1	1.00	0.96	0.93	0.91	0.92	0.88	0.85	0.84	0.83	0.70	0.70
x_2	1.00	0.95	0.93	0.89	0.84	0.83	0.84	0.85	0.84	0.72	0.71
x_3	1.00	0.97	0.95	0.90	0.89	0.83	0.80	0.78	0.73	0.64	0.61
x_4	1.00	0.94	1.00	0.99	0.96	0.90	0.87	0.83	0.79	0.72	0.65
x_5	1.00	0.88	0.91	0.87	0.84	0.81	0.77	0.73	0.71	0.57	0.52
x_6	1.00	0.95	0.91	0.90	0.85	0.80	0.74	0.70	0.67	0.59	0.55

4.3. Calculation of Correlation Coefficients and Degrees of Correlation

To find the difference series $\Delta X_i = |X_0(k) - X_i(k)|$ between the energy consumption series and the GDP series of each industry, the specific results are as follows:

$$\Delta X_1 = \{0.00,0.08,0.08,0.11,0.20,0.23,0.25,0.28,0.32,0.23,0.27\}$$

$$\Delta X_2 = \{0.00,0.07,0.07,0.09,0.12,0.18,0.24,0.29,0.32,0.26,0.28\}$$

$$\Delta X_3 = \{0.00,0.09,0.09,0.10,0.17,0.18,0.20,0.22,0.21,0.17,0.19\}$$

$$\Delta X_4 = \{0.00,0.06,0.14,0.19,0.24,0.25,0.27,0.27,0.28,0.25,0.22\}$$

$$\Delta X_5 = \{0.00,0.00,0.06,0.07,0.11,0.16,0.17,0.17,0.20,0.10,0.10\}$$

$$\Delta X_6 = \{0.00,0.07,0.06,0.10,0.13,0.15,0.14,0.14,0.16,0.12,0.13\}$$

Comparing the values of the above sequence of differences, it is found that the maximum value is 0.32 and the minimum value is 0. Take $\rho = 0.5$ and substitute it into the following equation:

$$\gamma_{(k)} = \frac{min|x_0(k) - x_i(k)| + \xi max|x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \xi max|x_0(k) - x_i(k)|}$$

The correlation coefficients and correlation degrees between energy consumption and economic growth of each industry are calculated according to the formula, and the results are shown in Table 3.

Table 3. Energy consumption industry structure correlation coefficient and correlation degree results

Year	2021	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011	P
γ_1	1.00	0.68	0.68	0.59	0.44	0.41	0.39	0.37	0.33	0.41	0.37	0.51
γ_2	1.00	0.69	0.71	0.63	0.57	0.47	0.40	0.36	0.33	0.38	0.36	0.54
γ_3	1.00	0.64	0.63	0.61	0.49	0.47	0.44	0.42	0.43	0.48	0.46	0.55
γ_4	1.00	0.73	0.53	0.45	0.40	0.39	0.37	0.37	0.37	0.39	0.42	0.49
γ_5	1.00	0.99	0.74	0.69	0.59	0.51	0.49	0.49	0.45	0.60	0.62	0.65
γ_6	1.00	0.69	0.74	0.63	0.55	0.51	0.53	0.53	0.50	0.57	0.55	0.62

From column 13 of Table 3, we can see that among the energy consumption and domestic energy consumption of all industries in China, transportation, warehousing and postal service is the industry with the smallest correlation between energy consumption and economic growth, with a correlation of 0.49, which is a non-significant correlation. The gray correlation between the remaining four major industries and domestic energy consumption and economic growth are 0.51, 0.54, 0.55, 0.65, 0.62, all greater than 0.5, which is a significant correlation, of which the wholesale and retail trade and accommodation, food and beverage industry energy consumption and the correlation with economic growth is the largest of 0.65, followed by the correlation of 0.62, again the correlation of 0.55, while agriculture, warehousing and postal industry is the smallest of all industries in terms of energy consumption and economic growth, its correlation is 0.49, which is a non-significant correlation. 0.55, and agriculture, forestry, animal husbandry, fisheries, water conservancy production activities and industrial energy consumption and economic growth is the weakest correlation of significance of 0.51 and 0.54, respectively.

5. Gray Correlation Analysis of China's Economic Growth and the Structure of Energy Consumption Varieties

5.1. Selection of Relevant Data

This part is to study the correlation coefficients and the degree of correlation between coal, oil, natural gas, and hydropower, nuclear power, and wind power in the structure of energy varieties and GDP before, so as to explore the relationship between the consumption of each energy type and economic growth. GDP is the reference series, whose unit is billions of yuan, and the four types of energy varieties are the comparative series, whose unit is ten thousand tons of standard coal. Coal consumption is denoted by x_1, oil consumption by x_2, natural gas consumption by x_3, and hydropower, nuclear power and wind power consumption by x_4, as shown in Table 4.

Table 4. GDP and Energy Consumption Variety Structure Data

Year	GDP (Billions)	Structure of energy consumption varieties (tons of standard coal)			
		Coal	Oil	Natural Gas	Hydroelectric, Nuclear, Wind Power
2021	1149237.00	293975.86	97816.66	46278.85	87824.63
2020	1013567.00	283540.67	93683.03	41858.38	79231.93
2019	986515.20	281280.58	92622.72	38999.04	74585.66
2018	919281.10	278435.75	89193.83	35866.30	68429.13
2017	832035.90	276231.16	86151.30	31452.06	61992.47
2016	746395.10	274608.02	82559.00	26931.01	57393.96
2015	688858.20	276964.09	79876.79	25178.55	52093.56
2014	643563.10	281843.77	74101.78	23986.70	48401.74
2013	592963.20	280999.36	71292.12	22096.39	42525.13
2012	538580.00	275464.53	68363.46	19302.62	39007.39
2011	487940.20	271704.19	65023.22	17803.98	32511.61

5.2. Raw Data Deprogramming

Using the 2021 data as a reference series the raw data on energy consumption in various categories collated from the statistical yearbook were processed in a dimensionless manner, and the data were standardized to be between 0 and 1. The processed data are shown in Table 5.

Table 5. Data dimensionless results

	2021	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011
GDP	1.00	0.88	0.86	0.80	0.72	0.65	0.60	0.56	0.52	0.47	0.42
x_1	1.00	0.96	0.96	0.95	0.94	0.93	0.94	0.96	0.96	0.94	0.92
x_2	1.00	0.96	0.95	0.91	0.88	0.84	0.82	0.76	0.73	0.70	0.66
x_3	1.00	0.90	0.84	0.78	0.68	0.58	0.54	0.52	0.48	0.42	0.38
x_4	1.00	0.90	0.85	0.78	0.71	0.65	0.59	0.55	0.48	0.44	0.37

5.3. Calculation of Correlation Coefficients and Degrees of Correlation

The difference series $\Delta X_i = |X_0(k) - X_i(k)|$ between the energy consumption series and the GDP series for each category is first derived as follows:

$$\Delta X_1 = \{0.00,0.08,0.10,0.15,0.22,0.28,0.34,0.40,0.44,0.47,0.50\}$$

$$\Delta X_2 = \{0.00,0.08,0.09,0.11,0.16,0.19,0.22,0.20,0.21,0.23,0.24\}$$

$$\Delta X_3 = \{0.00,0.02,0.02,0.02,0.04,0.07,0.06,0.04,0.04,0.05,0.04\}$$

$$\Delta X_4 = \{0.00,0.02,0.01,0.02,0.02,0.00,0.01,0.01,0.03,0.02,0.05\}$$

Comparing the values of the above sequence of differences, it is easy to see that the maximum value is 0.5 and the minimum value is 0. Take $\rho = 0.5$ and substitute it into Eq:

$$\gamma_{(k)} = \frac{\min|x_0(k) - x_i(k)| + \xi\max|x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \xi\max|x_0(k) - x_i(k)|}$$

The correlation coefficients and correlations between various categories of energy consumption and economic growth were calculated according to the formulae, and the results are shown in Table 6.

Table 6. Results of correlation coefficients and correlation degrees of the structure of energy consumption varieties

Year	2021	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011	P
γ_1	1.00	0.75	0.72	0.63	0.54	0.47	0.42	0.39	0.36	0.35	0.33	0.54
γ_2	1.00	0.77	0.74	0.69	0.61	0.56	0.54	0.56	0.54	0.52	0.51	0.64
γ_3	1.00	0.92	0.94	0.91	0.85	0.79	0.82	0.86	0.87	0.83	0.86	0.88
γ_4	1.00	0.93	0.96	0.92	0.93	0.98	0.98	0.97	0.89	0.91	0.82	0.94

From Table 6, it can be seen that natural gas is the energy source with higher correlation with economic growth among the above four energy sources, with a correlation of 0.88, second only to hydropower, nuclear power and wind power, mainly because natural gas is safer to use compared with coal and oil, and as a high-quality, efficient, green and clean low-carbon energy source, it does not produce harmful substances such as sulfur and dust, and can form a good complementary with the development of renewable energy sources. complement each other, effectively reducing air pollution. At the same time, the correlation between coal and oil and economic growth is small, respectively 0.54 and 0.64, but according to the relevant data, coal and oil are the two types of energy with the highest proportion of use in our country, which account for more than 74.5% of the total consumption of energy in our country, which indicates that the use of coal and oil is very inefficient, and cannot reasonably and effectively promote the development of the economy.

6. Responses and Recommendations

Energy consumption and economic growth have a high degree of correlation between the two, this paper through the analysis of China's energy consumption characteristics based on the use of gray correlation analysis to get China's gross domestic product and energy consumption varieties of structure, industrial structure of the gray correlation, according to the analysis of the structure of the proposed some relevant recommendations.

First, we must speed up the restructuring of industry and vigorously develop tertiary industries with high efficiency, low energy consumption and high services. Industry accounts for 66% of energy consumption in the various industrial structures, but the correlation between industry and economic growth is 0.54, which is a medium correlation. Wholesale, retail and catering industries and other industries in the various types of industrial structure of energy consumption accounted for only 3%, but the highest correlation with economic growth, amounting to 0.65; thus, it can be seen that China's industrial production in the consumption structure is still unreasonable. In the future process of economic development, the development of the tertiary industry, which is mainly high efficiency, low consumption and service-oriented, should be used to increase the proportion of energy that consumes less energy, and the transition from high consumption and low efficiency and high carbon emission to diversified and low-carbon green energy.

Secondly, promoting the development of the clean energy industry. Gray correlation analysis of economic growth and energy consumption structure shows that although China's economic development is still very dependent on coal, coal consumption still dominates in China's energy consumption, but the gray correlation between economic growth and coal consumption is smaller, which indicates that the problem of high energy consumption in China's economic development is still more prominent, and at the same time, the negative impacts of coal consumption on environmental pollution are also contrary to the green development concepts advocated by the government. The negative impact of coal consumption on environmental pollution is also contrary to the green development concept advocated, in view of which, China should actively adjust the industrial structure dominated by coal. Meanwhile, the analysis results show that the correlation between hydropower, nuclear power, wind power and natural

gas consumption and economic growth is very strong, as clean energy, China should continue to promote the development of hydropower, nuclear power, wind power and natural gas industry, and under the premise of ensuring the stability of the economy, gradually adjusting the energy structure, and gradually increase the proportion of energy consumption in the structure.

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