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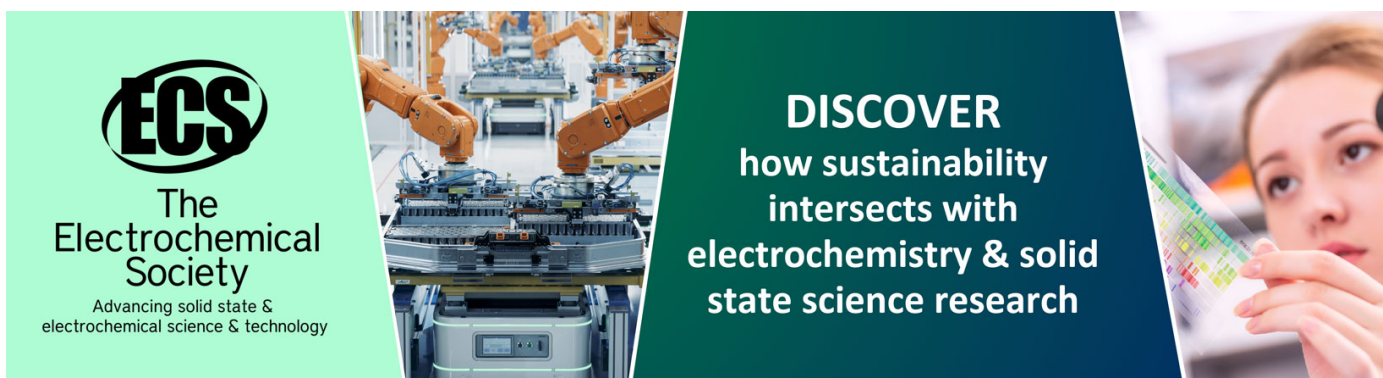
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Analysis of the Grey Correlation between Energy Consumption and Economic Growth in Fujian Province

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Abstract. Based on the data of energy consumption and economic growth in Fujian Province from 2007 to 2018, the correlation degree between energy consumption and economic growth is studied by using grey correlation analysis. The results show that the the gross domestic product (GDP) of Fujian Province is significantly correlated with the energy consumption products. The correlation degree is greater than 0.7. The order of the correlation degree is oil, coal, hydropower, wind power nuclear power and natural gas. The correlation is significant between the total amount of energy consumption and the value added of primary, secondary and tertiary industries in Fujian Province. The correlation degree is more than 0.6, indicating that the economic growth of Fujian Province is more dependent on energy consumption. Fujian Province should optimize its energy structure, vigorously develop clean energy and realize the development strategy of low-carbon economy.

1. Introduction

The relationship between economic growth and energy consumption is one of the core issues in resource economics. At present, Chinese scholars have carried out extensive research on the relationship between economic growth and energy consumption. There is an analysis method based on the grey correlation model. Li Xiaoyan[1] analyzed the relationship between industrial energy consumption and economic growth from the national level. The results show that the industries are significantly related to China's economic growth in industrial energy, which include the transportation and storage industry, wholesale retail trade and catering industry, agriculture forestry animal husbandry and water conservancy industry. From the local level, Wang Xingmin et al.[2] studied the correlation between industrial energy consumption and economic growth in Xinjiang. Wang Li et al.[3] conducted an empirical analysis on the correlation between industrial energy consumption and economic growth in Liaoning Province. The results show that the correlation between energy consumption and economic growth in different industries is significantly different. Liu Aiqin[4] made an empirical analysis on the relationship between energy utilization efficiency and terminal energy consumption and industrial GDP in Shandong Province by using the method of grey relative correlation degree. The results show that the total energy consumption is the key factor affecting economic growth. Wang Dong et al.[5] studied the grey correlation between energy consumption and economic growth based on the data of total energy consumption and energy consumption per unit GDP



in Tianjin. The results show that there is a significant positive correlation between energy consumption and economic growth. Wang Xin et al.[6] thought that the correlation between economic growth and energy consumption in Jilin Province is significant, and economic growth is strongly dependent on energy. Tapio decoupling elasticity index is also used to analyze the relationship between them. He Ze et al.[7] analyzed the dynamic relationship between China's energy consumption and economic growth. Liang Rizhong[8] studied the correlation between total energy consumption and economic growth in Shanghai. The results show that the overall decoupling between the two is weak. The cointegration analysis and the VAR error correction model are also used to study the relationship between them. Mali et al.[9] made an empirical study on the relationship between energy consumption and economic growth in Shanxi Province. The results show that there is a long-term cointegration relationship between them. Hu Junfeng et al.[10] analyzed the relationship between energy consumption and economic growth in Beijing by panel cointegration test. The results show that there is causal relationship between economic growth and short-term and long-term energy consumption. In the research of foreign scholars, Chontanawat Jaruwat[11] used the data of the association of Southeast Asian nations from 1971 to 2015 to study the dynamic relationship between energy consumption, carbon dioxide emissions and economic growth. The results show that there is a long-term relationship between these variables, and there is a causal relationship.

Fujian's economy has been growing steadily in recent years. GDP increased from 924.853 billion yuan in 2007 to 3580.404 billion yuan in 2018[12], with an average annual growth rate of 13.09%. At the same time, energy consumption is also increasing year by year with the process of urbanization and industrialization. The total energy consumption increased from 44.7172 million tons of standard coal in 2007 to 134.8 million tons of standard coal in 2018, with an average annual growth rate of 10.55%. The main energy consumption is coal and oil in Fujian Province. Coal and oil are polluting fossil energy, which cause great pressure on the ecological environment and have a certain impact on the sustainable and healthy economic development of Fujian Province. The self-sufficiency rate of primary energy was low before 2013 in Fujian Province. There was not any crude oil and natural gas, and with less coal and mineral resources. The energy productivity was far from meeting the growth of consumption demand. Oil coal and natural gas need to be imported from outside to meet the economic development needs. In recent seven years, Fujian Province has accelerated the transformation and upgrading of energy consumption structure. Priority should be given to the development of clean energy. The backward coal production capacity is gradually withdrawn. The refined oil supply is stable and orderly, and power supply is self-sufficient and surplus. Fujian Province has developed into a key national nuclear power region and a priority province for offshore wind power development.

The characteristics of grey correlation analysis method are clear ordering and concise operation. It does not limit the number of samples and the regularity of samples. It can make up for the deficiency of mathematical statistical methods such as principal component analysis, regression analysis and variance analysis[13]. It has certain advantages and practical application value, so it is widely used in various disciplines. In this paper, the grey correlation analysis method is used to study the correlation between energy consumption and economic growth in Fujian Province. It provides a theoretical basis to formulate low-carbon economic development strategy for Fujian Province.

2. Data sources and research methods

2.1 Data sources

2.1.1 Data of GDP and energy consumption products in Fujian Province

Fujian Province began to use natural gas energy in 2004, wind energy in 2007 and nuclear energy in 2013. According to the actual change of energy consumption structure in Fujian Province, this paper selects the statistical data of national economic accounting and energy consumption products in Fujian Province from 2007 to 2018. GDP (expressed by X_0 , unit: 100 million yuan) is selected as reference parameters. Coal consumption (X_1), oil consumption (X_2), natural gas consumption (X_3), hydropower

consumption (X_4) and wind power and nuclear power consumption (X_5) are selected as the parameters of comparison sequence. The unit of energy variable parameters is ten thousand tons of standard coal. Table 1 shows the original data of GDP and energy consumption products of Fujian Province from 2007 to 2018, and the data is from Fujian Statistical Yearbook-2019.

Table 1 Data of GDP and energy consumption products

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
X_0	9248.53	10823.01	12236.53	14737.12	17560.18	19701.78	21868.49	24055.76	25979.82	28519.15	32182.09	35804.04
X_1	4471.72	4841.61	5471.65	5090.94	6187.74	5983.76	6190.35	6251.02	5919.53	5163.44	5662.19	6524.32
X_2	1620.91	1554.57	1628.97	2278.98	2395.25	2462.67	2539.35	3042.95	2941.97	2864.57	3025.69	3033.00
X_3	7.11	23.20	116.95	385.96	459.09	503.01	632.11	672.28	605.00	649.94	665.40	687.48
X_4	1002.41	1299.35	1111.04	1396.79	868.28	1435.68	1209.73	1250.20	1328.63	1901.69	1242.92	997.52
X_5	7.11	15.47	25.06	36.76	69.86	94.31	326.96	577.93	1067.65	1456.35	1958.53	2237.68

2.1.2 Data of total energy consumption and added value of three industries in Fujian Province

The total energy consumption (X_0 , ten thousand tons of standard coal) is selected by referring to the series parameters. The added value of the first industry (X_1 , 100 million yuan), the added value of the second industry (X_2 , 100 million yuan) and the added value of the third industry (X_3 , 100 million yuan) are selected by comparing the parameters of the series. Table 2 is the original data of the added value of the first industry, the second industry and the tertiary industry and the total energy consumption in Fujian Province from 2007 to 2018[12].

Table 2 Data of total energy consumption and added value of three industries

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
X_0	7109.26	7734.20	8353.67	9189.42	9980.23	10479.44	10898.51	11794.37	11862.79	12035.99	12554.74	13480.00
X_1	1002.11	1158.17	1182.74	1363.67	1612.24	1776.71	1874.23	2014.80	2118.10	2363.22	2215.13	2379.82
X_2	4476.42	5318.44	6005.30	7522.83	9069.20	10187.94	11329.60	12515.36	13064.82	13844.96	15354.29	17232.36
X_3	3770.00	4346.40	5048.49	5850.62	6878.74	7737.13	8664.66	9525.60	10796.90	12310.97	14612.67	16191.86

2.2 Research method

2.2.1 Establish reference sequence (X_0) and comparison sequence (X_i)

$$X_0 = \{x_0(1), x_0(2), \dots, x_0(k)\} \quad (k=1, 2, \dots, m);$$

$$X_i = \{x_i(1), x_i(2), \dots, x_i(k)\} \quad (k=1, 2, \dots, n).$$

Where: $x_0(k)$ is the variables of the reference sequence, k is the time, m is the maximum value of time; $x_i(k)$ is the variables of the comparative sequence, i is the number of comparative sequences, n is the total number of comparative sequences.

2.2.2 Standardized treatment

The initial value operator is used to dimensionless the original sequence.

$$x'_0(k) = \frac{x_0(k)}{x_0} \quad (1)$$

$$x'_i(k) = \frac{x_i(k)}{x_i} \quad (2)$$

$$X'_0 = \{x'_0(1), x'_0(2), \dots, x'_0(k)\};$$

$$X'_i = \{x'_i(1), x'_i(2), \dots, x'_i(k)\}.$$

Where: $x'_0(k)$ and $x'_i(k)$ are the variables of reference sequence and comparison sequence after dimensionless treatment; X'_0 is the reference sequence after dimensionless treatment of X_0 , X'_i is the comparative sequence after dimensionless treatment of X_i .

2.2.3 Calculate the absolute difference between the comparison sequence and the reference sequence [$\Delta_i(k)$]

$$\Delta_i(k) = |x'_i(k) - x'_0(k)| \quad (i=1,2,\dots,n) \quad (3)$$

The absolute difference is listed as follows: $\Delta_i = \{\Delta_i(1), \Delta_i(2), \dots, \Delta_i(k)\}$.

2.2.4 The correlation coefficient (r_i) and correlation degree (ρ_i) were calculated

$$r_i = (\Delta_{\min} + \theta \Delta_{\max}) / (\Delta_i(k) + \theta \Delta_{\max}) \quad (4)$$

$$\rho_i = \frac{1}{k} \sum_{k=1}^m r_i \quad (5)$$

Where: $\Delta_{\min}$ and $\Delta_{\max}$ are the minimum and maximum absolute differences between the comparison sequence and the reference sequence. θ is the resolution coefficient. The larger θ is, the smaller the resolution is, generally $\theta \in [0,1]$ [13]. When $\theta=0.5$, if the correlation between the comparison sequence and the reference sequence is greater than 0.6, it can be considered significant [1-6]. If $\rho_1 < \rho_2$, the comparison sequence X_2 is more similar to the reference sequence X_0 , so the correlation between them is greater.

3. Results and analysis

3.1 Correlation analysis between GDP and energy consumption products

Based on the relevant data of GDP and energy consumption in Fujian Province in 2007, the variables in Table 1 are dimensionless. According to the absolute difference data between the reference sequence and the comparison sequence, the calculation results show that $\Delta_{\max}$ is 310.8516 and $\Delta_{\min}$ is 0. Therefore, take $\theta = 0.5$, and calculate the correlation coefficient and correlation degree between GDP and energy consumption products of Fujian Province by formula (4) and (5). The calculation results are shown in Table 3.

Table 3 Correlation coefficient between GDP and energy consumption products

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	ρ
r_1	1.0000	0.9994	0.9993	0.9970	0.9966	0.9949	0.9937	0.9923	0.9905	0.9877	0.9859	0.9847	0.9935
r_2	1.0000	0.9986	0.9979	0.9987	0.9972	0.9960	0.9948	0.9953	0.9936	0.9916	0.9897	0.9872	0.9951
r_3	1.0000	0.9867	0.9113	0.7468	0.7126	0.6937	0.6423	0.6282	0.6538	0.6376	0.6330	0.6260	0.7393
r_4	1.0000	0.9991	0.9986	0.9987	0.9934	0.9955	0.9926	0.9913	0.9905	0.9924	0.9857	0.9818	0.9933
r_5	1.0000	0.9935	0.9860	0.9775	0.9514	0.9331	0.7808	0.6639	0.5133	0.4351	0.3636	0.3333	0.7443

There is a close relationship between GDP and energy consumption products in Fujian Province. The correlation degree between five energy consumption products and GDP is greater than 0.7, which indicates that the correlation between economic growth and energy consumption is significant. The correlation degree of oil is the largest and that of natural gas is the smallest. The order of correlation degree is oil, coal, hydropower, wind power nuclear power and natural gas. The contribution rate of oil, coal and hydropower consumption to GDP of Fujian Province is large, and the correlation degree is greater than 0.9. Considering the proportion of energy consumption, Fujian's GDP is the most dependent on oil and coal consumption. For example, the average annual oil consumption accounted for 23.25% of the total energy consumption, and the average annual consumption of coal accounted for 55.13% of the total energy consumption in 2007-2018. Due to the limitation of water resources, the consumption of hydropower has decreased significantly in recent two years. Natural gas consumption is increasing year by year, but the growth rate is not large. Wind power nuclear power capacity has been steadily increasing year by year. Especially since 2013, Fujian has made a major breakthrough in energy construction, and Ningde nuclear power and Fuqing nuclear power have been put into operation. Nuclear power consumption has increased from 2.1% in 2013 to 14.6% in 2018.

As can be seen from Fig.1, Fujian Province has adopted a series of energy-saving measures, as well as the optimization and improvement of energy structure. The proportion of coal consumption has shown a downward trend, and oil consumption is relatively stable. The overall consumption proportion of clean energy natural gas, hydropower, wind power and nuclear power is increasing year

by year. The energy consumption per unit GDP has decreased from 0.82 in 2007 to 0.46 in 2018 (ten thousand tons of standard coal / 100 million yuan).

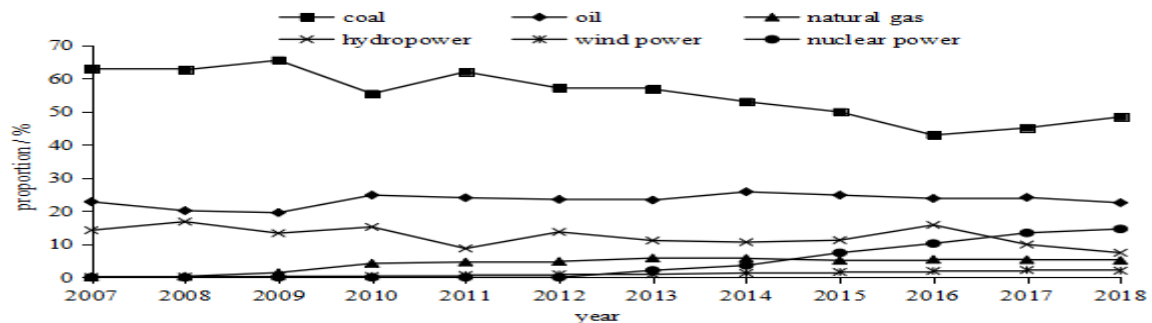


Fig.1 Proportion of energy consumption products in total energy consumption

3.2 Analysis on the correlation between total energy consumption and three industries

The dimensionless treatment of the variable series in Table 2 is carried out. The absolute difference between the reference sequence and the comparison sequence is calculated, and the $\Delta_{\max}$ is 2.3988 and $\Delta_{\min}$ is 0. Taking $\theta=0.5$, the calculation results of correlation coefficient and correlation degree between total energy consumption and added value of primary industry, secondary industry and tertiary industry in Fujian Province are shown in Table 4.

Table 4 Correlation coefficient between total energy consumption and three industries

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	ρ
r_1	1.0000	0.9464	0.9956	0.9461	0.8540	0.8005	0.7805	0.7733	0.7293	0.6432	0.7296	0.7147	0.8261
r_2	1.0000	0.9229	0.8781	0.7556	0.6584	0.5993	0.5458	0.5133	0.4896	0.4614	0.4188	0.3804	0.6353
r_3	1.0000	0.9486	0.8796	0.8222	0.7402	0.6747	0.6104	0.5802	0.5008	0.4326	0.3624	0.3333	0.6571

The correlation degree between the added value of the three industries and the total energy consumption in Fujian Province is greater than 0.6. It shows that there is a significant correlation between industrial economic growth and energy consumption. The order of correlation degree is the first industry, the third industry and the second industry. The correlation between the added value of the primary industry and energy consumption is the largest, indicating that the primary industry is closely related to energy consumption. For example, Fujian's agriculture, forestry, animal husbandry, fishery and water conservancy consumed 2.3558 million tons of energy in 2017. Energy consumption only accounts for 1.88% of the total energy consumption, but the output value accounts for 7.13% of GDP. It shows that the energy utilization rate of the primary industry is high. Fujian Province can increase the development of the primary industry with low energy consumption.

The correlation between the added value of the tertiary industry and the total energy consumption is the second. For example, Fujian Province's transportation, storage and postal industry consumed 12.191 million tons of energy, and the wholesale, retail, accommodation and catering industries consumed 3.4815 million tons of energy in 2017. Their consumption accounts for 12.42% of the total energy consumption, but the output value accounts for 14.75% of GDP. It shows that the energy consumption of the tertiary industry is not large, and there is still a large space for development.

The correlation between the added value of the secondary industry and the total energy consumption is relatively low. Fujian Province consumed 84.1506 million tons of industrial energy and 2.696 million tons of construction industry in 2017. Their consumption accounts for 69.17% of the total energy consumption, but the output value only accounts for 47.80% of GDP. It shows that the energy utilization rate of the secondary industry is not high. It is to develop industrial economy through high energy consumption. This traditional development model will lead to the increase of environmental constraints. For example, the total amount of industrial waste gas emission in Fujian Province was 974.7 billion standard cubic metre in 2007, and increased to 1713.9 billion standard cubic metre in 2017. The average annual growth rate was 5.81%.

4. Conclusion and suggestion

There is a significant correlation between GDP and energy consumption products in Fujian Province.

The order of correlation degree is oil, coal, hydropower, wind power nuclear power and natural gas.

The consumption proportion of wind power and nuclear power is increasing year by year. The energy utilization rate of the primary industry is high, but the energy utilization rate of the secondary industry is not high. The economic growth of Fujian Province is strongly dependent on fossil energy such as coal and oil. It is not conducive to the development of low-carbon economy and environmental protection. Therefore, the energy consumption structure of Fujian Province needs to be further optimized. Based on the current situation of energy consumption structure in Fujian Province, this paper puts forward the following countermeasures and suggestions.

4.1 Optimize the energy structure and accelerate the development of clean energy

Fujian Province has unique comprehensive advantages in developing new energy. It is located in the southeast coast, with abundant wind energy resources and favorable conditions for nuclear power construction. Fujian Province should accelerate the transformation and upgrading of energy consumption, and actively create low-carbon energy and low-carbon industrial system. Fujian Province should vigorously develop renewable energy and clean energy, promote the development and utilization of green energy, and increase the proportion of natural gas, hydropower, wind power, nuclear power and other clean energy, so that the development and use of energy are in line with the concept of green environmental protection.

Fujian Province vigorously developed nuclear power from 2013 to 2018. The average annual growth of nuclear power consumption was 53.8%. At present, Ningde nuclear power station, Fuqing nuclear power station and Zhangzhou nuclear power station under construction are in total three nuclear power stations. However, the proportion of natural gas and wind power consumption in total energy consumption has been very low. Fujian Province should seriously analyze the main problems existing in the market, play the role of policy leverage, and actively promote the development and management of natural gas and wind power through price structure adjustment. Under the condition that the hydropower resources have been basically developed in Fujian Province, the development of hydropower resources should be standardized scientifically to promote the full utilization of hydropower resources. Solar power generation is the most economical energy in the future. So far, solar energy has not been widely used in Fujian Province, so we should encourage the development of solar energy industry.

4.2 Strengthen environmental protection and control the emission of air pollutants

In recent 10 years, energy consumption per unit GDP of Fujian Province has decreased year by year. The annual energy consumption increment does not exceed 10 million tons. Low energy consumption has supported the medium and high speed development of economy. Although the energy consumption per unit GDP and air pollutant emissions in Fujian Province are lower than the national average level. However, the process of urbanization and industrialization in Fujian Province accelerated during the 13th Five Year Plan period, A large number of major industrial projects have been implemented, which will promote the sustained and rapid growth of energy demand. Fossil energy consumption is still the main part of energy structure. The environmental protection problems caused by energy production and consumption are becoming increasingly prominent. Energy saving and emission reduction targets are more difficult.

Therefore, Fujian Province should focus on petroleum, thermal power generation, building materials, steel, chemical industry and other industries according to the actual situation. Fujian Province should make every effort to promote energy conservation and consumption reduction, eliminate backward production capacity, complete the energy-saving transformation of coal-fired power units on schedule. Fujian Province should strictly control the total energy consumption, and effectively control the carbon emission of power and other energy industries. Fujian Province should further promote the emission reduction and control of major pollutants, strengthen the restriction of

pollution emission standards and source prevention and control, and actively promote the use of low-carbon technology. These countermeasures will provide strong support for the construction of ecological civilization and the development of low-carbon economy in Fujian Province.

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