Analysis of the Factors Affecting Economic Growth by Energy Consumption and Energy Structure in Sichuan Province—Based on Grey Relation Analysis of Mathematical Model

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Abstract: This paper uses the grey correlation analysis method commonly used in mathematical modeling to dynamically analyze the relationship between GDP and energy consumption and energy structure in Sichuan. Influenced by such factors as the global climate edge and the energy crisis, the dialectical relationship between energy consumption, energy structure and economic growth is facing new adjustments. There is a general trend for all regions to change their economic development concepts. This paper collects the relevant data of Sichuan, China, and calculate the gray correlation between economic development and energy consumption. Among all kinds of energy consumption in Sichuan, the correlation degree of one-time electricity is 0.794, ranking first. The consumption structure of the four energy products has been continuously optimized by the economic development of Sichuan, which is consistent with the factor endowment rich in water resources and natural gas resources in Sichuan. Among the energy consumption industries in Sichuan, the correlation degree of energy consumption in the construction industry is the largest 0.763, ranking first. So, the development of the construction industry is the key factor affecting the economic growth in Sichuan.

Keywords: Energy Consumption，Mathematical Model，SPSSpro，Grey Relation Analysis.

1. INTRODUCTION

Energy promotes economic growth, but the generation of air pollutants, water pollutants and solid wastes after energy consumption will affect the carrying capacity of the regional ecological environment. With the increase of energy consumption, the non-renewable resources will be exhausted. In the context of the goal of carbon peaking and carbon neutralization, there is a long way to go to develop new energy and achieve sustainable economic growth.

Liu Rongmao et al. (2006) studied the relationship between industrial wastewater, waste gas and solid pollutant emissions from energy consumption and economic development, and believed that energy consumption would lead to environmental pollution, reduce energy consumption, and help improve the environment and adjust the industrial structure [1]. Wang Huogen et al. (2007) believed that there was spatial autocorrelation between provincial energy consumption and economic growth [2]. Lee&Chang (2008) found that there was a two-way causal relationship between GDP and consumption of energy [3]. Balcilar M et al. (2010)

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studied the relationship between energy consumption and GDP in European countries, and concluded that Canada's energy consumption can predict its own economic growth [4]. Ma Li et al. (2016) used the cointegration analysis method to study that there was a long-term cointegration relationship between energy consumption and GDP in Shaanxi Province, but there is no two-way Granger causality [5]. Bataille &Melton (2017) studied that improving energy efficiency would promote GDP growth [6]. Liu Yao (2018) collected the data of China's energy consumption and economic development level from 2004 to 2016 and analyzed them with IPAT model to find that economic growth and energy consumption are relatively decoupled in most years [7]. Du Junhui et al. (2021) used the grey correlation and Tapio decoupling analysis methods to analyze that Hebei's economic growth and energy consumption had a significant grey correlation, and Hebei's GDP had long depended on various energy consumption [8].

To sum up, at present, domestic and foreign scholars have conducted relevant research on the relationship between energy consumption and GDP. However, there is little research on the grey correlation between energy consumption and GDP in Sichuan Province. This paper uses the grey correlation analysis method in the mathematical modeling to analyze the relationship between GDP and energy consumption in Sichuan Province and judge the importance of each factor.

2. METHODS

In 1982, Deng Julong, a scholar, put forward the Grey Relation Analysis (GRA) principle. This principle is a multi-factor statistical analysis method. The method judges the degree of correlation between factors according to the similarity of the geometric shape of the change curve of each factor. This method completes the comparison of the geometric relationship of the relevant statistical data of the time series in the system through the quantitative analysis of the development trend of the dynamic process, and calculates the grey correlation between the reference sequence and the comparison sequence. This method makes up for the defects of small sample, discrepancy between qualitative analysis and quantitative analysis. The specific calculation steps are as follows:

2.1 Definite sequence

Set reference sequence Y_{0t}, compare sequence Y_{it}.

t indicates different periods and i indicates different sequences.

2.2 Dimensionless processing

Since the data in the reference series and comparison series may draw correct conclusions due to different weights and measures, and the data is dimensionless, this paper selects the initial value processing method to divide the series data by the value of the first period of each variable.

$$y_{0t} = \frac{Y_{0t}}{Y_{01}} \tag{1}$$

$$y_{it} = \frac{Y_{it}}{Y_{i1}} \tag{2}$$

t represents different periods, and i represents different categories.

2.3 Calculate correlation coefficient

$$\varphi_{it} = \frac{\min_t \min_i |Y_{0t}-Y_{it}| + \rho \cdot \max_t \max_i |Y_{0t}-Y_{it}|}{|Y_{0t}-Y_{it}| + \rho \cdot \max_t \max_i |Y_{0t}-Y_{it}|} \tag{3}$$

ρ is the resolution coefficient, $\rho \in (0,1)$, normally 0.5.

2.4 Calculate of correlation degree

The grey relational degree ϑ_i is the average value of the correlation coefficient.

$$\vartheta_i = \frac{1}{n} \cdot \sum_{i=1}^{n} \varphi_{it} \tag{4}$$

2.5 Relevance ranking

ϑ_i is sorted in ascending order. The bigger ϑ_i is, the closer the connection will be.

3. THE MATHEMATICAL ANALYSIS PROCESS OF GDP AND ENERGY CONSUMPTION CATEGORY STRUCTURE IN SICHUAN

3.1 Data resources

The data in this paper are from Sichuan Statistical Yearbook [9] and China Statistical Yearbook [10] from 2011 to 2020. The reference sequence selects the GDP of Sichuan (Y_0). The comparison sequence selects the equivalent value of four types of energy consumption in Sichuan, namely coal (Y_1), crude oil (Y_2), natural gas (Y_3) and one-time electricity (Y4). For example, the GDP of Sichuan Province in 2011 is expressed as Y_{01}, the equivalent value of coal consumption in Sichuan Province in 2011 is expressed as Y_{11}.

Table 1: GDP and the four types of energy consumption of Sichuan from 2010 to 2021

Year/t	Y_0	Y_1	Y_2	Y_3	Y_4
2011/1	21050.87	8790.68	2635.11	2061.10	1804.53
2012/2	23922.41	9639.78	2843.79	2034.40	1899.54
2013/3	26518.02	9556.9	3523.5	1972.4	2487.8
2014/4	28891.33	8500.1	3930.1	2196.8	3064.3
2015/5	30342.01	7539.3	4355.5	2274.0	3415.7
2016/6	33138.48	6365.4	3563.1	2695.4	3712.3
2017/7	37905.14	6085.1	3711.6	2876.3	3951.9
2018/8	42902.10	5865.3	3680.7	3152.2	4087.9
2019/9	46363.75	5886.1	3881.8	3387.7	4197.5
2020/10	48598.76	5728.9	3729.6	3486.6	4491.5

3.2 Dimensionless processing of raw data

Because the dimensions of each variable are different, in order to increase comparability , so the data in Table 1 are dimensionless treated by Formula 1 and Formula 2, as shown in Table 2.

For example, the dimensionless treatment of Sichuan's GDP in 2015 is as follows.

$$y_{05} = \frac{Y_{0t}}{Y_{01}} = \frac{Y_{05}}{Y_{01}} = \frac{30342.01}{21050.87} = 1.441$$

For example, the dimensionless treatment of equivalent value of coal consumption in Sichuan Province in 2015 is as follows.

$$y_{15} = \frac{Y_{it}}{Y_{i1}} = \frac{Y_{15}}{Y_{11}} = \frac{7539.3}{8790.68} = 0.858$$

Table 2: Dimensionless processing results of original data

Year/t	y_0	y_1	y_2	y_3	y_4
2011/1	1	1	1	1	1
2012/2	1.136	1.097	1.079	0.987	1.053
2013/3	1.260	1.087	1.337	0.957	1.379
2014/4	1.372	0.967	1.491	1.066	1.698
2015/5	1.441	0.858	1.653	1.103	1.893
2016/6	1.574	0.724	1.352	1.308	2.057
2017/7	1.801	0.692	1.409	1.395	2.190
2018/8	2.038	0.667	1.397	1.529	2.265
2019/9	2.202	0.670	1.473	1.644	2.326
2020/10	2.309	0.652	1.415	1.692	2.489

3.3 Calculate correlation coefficient

The author applies the data processing software Scientific Platform Serving for Statistics Professional (SPSSpro) and the grey correlation analysis function in the comprehensive evaluation analysis in the data analysis toolbar of the data processing platform to process the data.

In the system, the GDP of Sichuan is put into the parent series, and the consumption of coal, crude oil, natural gas and one-time electric power in Sichuan from 2011 to 2020 which is put into the characteristic series. In order to eliminate the influence of various variables due to different weights and measures on subsequent analysis, because the data shows obvious increasing or decreasing characteristics, the author uses the initial value method to dimensionless process the serial data.

Resolution coefficient ρ, the smaller is, the greater is the resolution. The value of ρ in this paper is 0.5. The software calculates the correlation coefficient according to Formula 3, as shown in the table 3. The correlation coefficient represents the value of the correlation degree that affects the four major energy consumption and regional economic growth in the corresponding dimensions. The larger the number, the more correlation.

Table 3. Results of grey correlation coefficient between Sichuan GDP and energy consumption

Year/t	φ_1	φ_2	φ_3	φ_4
2011/1	1	1	1	1
2012/2	0.954	0.935	0.847	0.908
2013/3	0.828	0.915	0.732	0.874
2014/4	0.671	0.874	0.730	0.718
2015/5	0.587	0.797	0.710	0.647
2016/6	0.494	0.789	0.757	0.632
2017/7	0.428	0.679	0.672	0.680
2018/8	0.377	0.564	0.620	0.785
2019/9	0.351	0.532	0.597	0.870
2020/10	0.333	0.481	0.573	0.821

3.4 Calculate correlation Degree

Use Formula 4 to calculate the grey correlation degree and rank it. The results are shown in Table 4, fully demonstrating the relationship between the four main energy consumption and the regional economy.

Table 4. Results of correlation degree

Evaluation items	Symbols	Relevance	Rank
Hydropower	ϑ_4	0.794	1
Oil Fuel	ϑ_2	0.757	2
Natual Gas	ϑ_3	0.724	3
Coal Products Fuel	ϑ_1	0.602	4

4. THE PROCESS OF MATHEMATICAL ANALYSIS OF SICHUAN`S GDP AND ENERGY CONSUMPTION IN THE SIX INDUSTRIES

4.1 Data sources

The author selects the GDP of Sichuan (Y_0) as the reference sequence. The comparison sequences select the energy consumption of agriculture, forestry, animal husbandry, fishery (Y_5), industry (Y_6), construction (Y_7), transportation, warehousing and postal services (Y_8), wholesale and retail, accommodation and catering (Y_9), and residents' living industries (Y_{10}).

Table 5: GDP and Energy consumption in six industries of Sichuan from 2010 to 2021

Year/t	Y_0	Y_5	Y_6	Y_7	Y_8	Y_9	Y_{10}
2011/1	21050.87	270.15	14096.40	373.86	1281.00	668.33	2395.10
2012/2	23922.41	289.73	14575.00	419.00	1376.00	664.18	2622.00
2013/3	26518.02	292.74	14002.52	368.39	930.32	616.38	1891.90
2014/4	28891.33	290.09	14191.03	419.17	1253.84	746.56	2238.46
2015/5	30342.01	299.05	13937.68	439.79	1265.47	764.38	2365.35
2016/6	33138.48	330.77	11915.45	558.68	1640.46	767.49	2633.08
2017/7	37905.14	347.27	11924.45	594.33	1753.44	812.82	2819.06
2018/8	42902.10	360.67	12053.03	631.04	1813.35	891.84	3072.75
2019/9	46363.75	365.86	12614.37	653.34	1909.39	926.11	3194.58
2020/10	48598.76	369.46	12892.69	643.93	1814.71	894.21	3370.40

4.2 Dimensionless processing of raw data

Because the dimensions of variables are different, in order to increase comparability , so the data in Table 5 are dimensionless treated by Formula 1 and Formula 2, as shown in Table 6.

For example, the dimensionless treatment of industrial energy consumption in Sichuan Province in 2015 is as follows

$$y_{65} = \frac{Y_{it}}{Y_{i1}} = \frac{Y_{65}}{Y_{61}} = \frac{13937.68}{14096.40} = 0.989$$

Table 6: Dimensionless processing results of original data

Year/t	y_0	y_5	y_6	y_7	y_8	y_9	y_{10}
2011/1	1	1	1	1	1	1	1
2012/2	1.136	1.072	1.034	1.121	1.074	0.994	1.095
2013/3	1.260	1.084	0.993	0.985	0.726	0.922	0.790
2014/4	1.372	1.074	1.007	1.121	0.979	1.117	0.935
2015/5	1.441	1.107	0.989	1.176	0.988	1.144	0.988
2016/6	1.574	1.224	0.845	1.494	1.281	1.148	1.099
2017/7	1.801	1.285	0.846	1.590	1.369	1.216	1.177
2018/8	2.038	1.335	0.855	1.688	1.416	1.334	1.283
2019/9	2.202	1.354	0.895	1.748	1.491	1.386	1.334
2020/10	2.309	1.368	0.915	1.722	1.417	1.338	1.407

4.3 Calculate correlation coefficient

For the dimensionless data in Table 6, the author uses Formula 3 to calculate the grey correlation coefficient. The correlation coefficient represents the value of the correlation degree that affects the energy consumption of the six major industries and the regional economic growth in the corresponding dimensions. The results are shown in Table 7.

Table 7. Results of correlation coefficient of energy consumption in six industries

Year/t	φ_5	φ_6	φ_7	φ_8	φ_9	φ_{10}
2011/1	1	1	1	1	1	1
2012/2	0.916	0.872	0.978	0.918	0.830	0.944
2013/3	0.798	0.724	0.718	0.566	0.674	0.597
2014/4	0.700	0.656	0.735	0.639	0.732	0.614
2015/5	0.676	0.606	0.725	0.606	0.701	0.606
2016/6	0.666	0.489	0.897	0.704	0.621	0.595
2017/7	0.575	0.422	0.768	0.617	0.544	0.528
2018/8	0.498	0.371	0.666	0.528	0.498	0.480
2019/9	0.451	0.348	0.605	0.495	0.460	0.445
2020/10	0.426	0.333	0.543	0.439	0.418	0.436

4.4 Calculate correlation Degree

Use Formula 4 to calculate the grey correlation degree and rank it. The results are shown in Table 4, fully demonstrating the relationship between energy consumption of six industries and regional economy.

Table 8. Results of correlation degree

Evaluation items	Symbols	Relevance	Rank
Construction	ϑ_7	0.763	1
Agriculture, Forestry, Animal Husbandry and Fishery	ϑ_5	0.671	2
Transport, Storage and Post	ϑ_8	0.651	3
Wholesale and Retail Trades, Hotels and Catering Services	ϑ_9	0.648	4
Household Consumption	ϑ_{10}	0.624	5
Industry	ϑ_6	0.582	6

5. CONCLUSIONS AND SUGGESTIONS

Grey correlation analysis judges the correlation degree between parent series and sub series through the geometric similarity of the curves of parent series and compare series of the system.

According to the results of Table 4 shows that $\vartheta_4 > \vartheta_2 > \vartheta_3 > \vartheta_1 > 0.5$, the total consumption of the four types of energy products has a significant impact on the GDP of Sichuan. Among them, the correlation degree of the one-time electricity consumptionis 0.794, ranking first. The correlation degree values of crude oil and natural gas are 0.757 and 0.724, ranking second and third respectively. The coal correlation degree is the smallest, lower than 0.7. It can be seen that the consumption structure of the four energy products has been continuously optimized by the economic development of Sichuan, which is consistent with the factor endowment rich in water resources and natural gas resources in Sichuan. So, Sichuan Province may make full use of regional water resources and continuously develop renewable resources.

It can be seen from Table 8 that $\vartheta_7>\vartheta_5>\vartheta_8>\vartheta_9>\vartheta_{10}>\vartheta_6>0.5$ which indicates that the energy consumption in the six industries have a significant impact on the economic development of Sichuan. The energy consumption of the construction industry has the highest correlation of 0.763, ranking first. The correlation coefficient values of agriculture, forestry, fishery and animal husbandry, transportation, storage and postal services, wholesale and retail, catering and living consumption are 0.671, 0.652, 0.648 and 0.624 respectively, all above 0.6. It can be concluded that the GDP of Sichuan is still a connotative development path, belonging to a major agricultural province. The value of industrial correlation degree is 0.582, and the correlation degree between industry and regional economic development is the smallest among the six industries, indicating that there is a large growth space for Sichuan industry to promote regional economic development. All parts of the region give full play to their regional industrial advantages, optimize and adjust the industrial structure to promote sustainable economic development.

REFERENCES

[1] Liu Rongmao, Zhang Lixia, Meng Lingjie. Economic Growth and Environmental Quality: Evidence from China's Inter provincial Panel Data .Economic Geography, 2006, 26(3) ： 374 - 377.

[2] Wang Huogen, Shen Lisheng. A Spatial Panel Statistical Analysis on Chinese Economic Growth and Energy Consumption . Journal of Quantitative & Technological Economics. 2007, (12):98-107.

[3] Lee C, Chang P. Energy consumption and economic growth in Asian economies: A more comprehensive analysis using panel data . Resource & Energy Economics, 2008, 30(1):50-65.

[4] Balcilar M, Ozdemir Z, Arslanturk Y. Economic growth and energy consumption causal nexus viewed through a bootstrap rolling window . Energy Economics, 2010, 32 (6):1398-1410.

[5] Ma Li, Ye Qiang-qiang. Empirical Study on Relationship between Energy Consumption and Economic Growth—the case of Shaanxi Province .Economic Geography, 2016, 36 (06):130-135.

[6] Bataille C, Melton N. Energy efficiency and economic growth: A retrospective CGE analysis for Canada from 2002 to 2012. Energy Economics, 2017, 64 (5):118-130.

[7] Liu Xiao. An Empirical Analysis of the Relationship between Economic Growth and Energy Consumption .Statistics & Decision, 2018, 34 (8):141-144.

[8] Du Junhui, Wang Hongxia, Liu Wei. Research on the relationship between energy consumption and economic growth in Hebei province . Journal of North China Institute of Science and Technology, 2021, 18 (5):92-99.

[9] http://tjj.sc.gov.cn/scstjj/c105855/nj.shtml.

[10] http://www.stats.gov.cn/tjsj/ndsj/.