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Research On Energy Consumption of China's Jiangsu Province Based on Gray System Theory

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Abstracts

The total energy consumption data of China's Jiangsu Province from 2016 to 2022 are selected, and the GM(Grey Model)(1,1) in grey system theory is applied to forecast the total energy consumption of Jiangsu Province from 2023 to 2027. It is predicted that the energy consumption of China's Jiangsu Province will be a continuous growth tendency during 2023-2027.The total energy consumption of Jiangsu Province will be 403.96 million tons of standard coal in 2027, and the average annual growth rate is still growing. The grey relation analysis is conducted to examine the relationship between total energy consumption and factors such as GDP (Gross Domestic Product), industrial output value, total population, and disposable income per capita of residents in Jiangsu Province. The total population has the largest correlation with the total energy consumption, and the correlation between industrial output value, per capita disposable income of residents, and GDP (Gross Domestic Product) with energy consumption is the second, with no significant difference in correlation among them. Finally, based on the prediction results of GM(1,1) and the grey relation analysis results, this paper gives a basis of energy consumption policies in Jiangsu Province and offers corresponding suggestions to achieve the goals of energy conservation and sustainable energy using in future.

Keywords: GM(1,1); Energy consumption; Grey prediction; Grey relation

1. Introduction

With the rapid development of the global economy, China's energy consumption has increased rapidly and become the largest country in energy consumption. As a leading province in the country's economic development, Jiangsu Province's energy demand is also increasing due to the continuous expansion of the economic scale. Energy consumption in Jiangsu Province is dominated by industrial production, accounting for 70% of the total energy consumption[1]. Additionally, coal is the primary source of energy consumption. In 2018, the coal consumption in Jiangsu Province was as high as 254,072,800 tons, ranking fifth in China[2]. Given the enormous energy consumption, the scientific prediction of future energy consumption in Jiangsu Province and an analysis of its energy consumption structure hold great practical significance for rationalizing energy consumption planning and adjusting the energy mix.

In recent years, a number of scholars have already carried out research on energy consumption using a variety of models. Chen Hongtao et al.[3] established a GM(1,1) model for energy consumption between 20 years in China with a fitting accuracy of 94.53%(Chen Hongtao&Zhou Dequn, 2007). Chai Yan et al.[4] proposed an improved residual-type GM(1,1)-LSSVM prediction model to predict the total coal energy consumption in Liaoning Province between 10 years(Chai Yan&Liu Xiangyu, 2014). Xie Xiaojun et al.[5] proposed a combined model based on ARIMA and BP neural network to predict the energy consumption in Guangxi Province, and the mean relative error of the prediction results was only 1.01% in absolute value(Xie Xiaojun et al.,2019). Zhang Song et al.[6]based on EMD(Empirical Mode Decomposition) analysis, combined with SVM(Support Vector Machines) method to establish China's energy consumption prediction model, to provide new ideas for energy consumption prediction(Zhang Song&Jin Liang, 2011). Based on grey system theory, this paper selects the total energy consumption of Jiangsu Province from 2016 to 2022, establishes a GM(1,1) model, predicts the total energy consumption of Jiangsu Province from 2023to 2027, and carries out a grey relation analysis of the energy consumption structure, which provides scientific references for the energy consumption planning of Jiangsu Province.

2. Forecast of Energy Consumption in Jiangsu Province based on GM(1,1)

2.1 GM(1,1) Fundament

The GM(1,1) model is the most widely used model in the GM series model, which is the basic model of grey prediction theory. The GM(1,1) model accumulates the discrete original series data to generate a new series with strong regularity and builds a first-order differential equation model. It then makes the least-squares estimation and reduces the computed value to the predicted value by accumulating and subtracting the computed value. Finally, it checks the accuracy and error of the model. The establishment of the grey prediction model for first-order variables involves four steps: grey sequence generation, exponential law test, model parameter estimation and model error test.(Yang Hualong et al.,2011)[7].

2.2 GM(1,1) Modeling Process

(1)Generate initial data.Let the original sequence $x^{(0)}=(x^{(0)}(1), x^{(0)}(2), \cdots, (x^{(0)}(n))$

1-AGO for $x^{(0)}$,generate new sequence X（1）：$X^{(1)}=(x^{(1)}(1), x^{(1)}(2), \cdots, x^{(1)}(n))$，included among these

$$x^{(1)}(k)=\sum_{i=1}^{k} x^{(0)}(i)(k = 1,2, \ldots, n) \quad (1)$$

(2)Exponential regularity test.A quasi-smoothness test is performed on $X^{(0)}$:

$$\rho（k）= \frac{x^{(0)}(k)}{x^{(1)}(k-1)} \in [0,0.5] \quad (2)$$

Quasi-exponential law test for $X^{(1)}$

$$\sigma(k) = \frac{x^{(1)}(k)}{x^{(1)}(k-1)} [1,1.5], \ k \geq 2 \quad (3)$$

The above are the necessary conditions to build the GM(1,1) model.

(3)Establish a first order differential equation. Establish the equation for $x^{(1)}(k)$ as

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = b \quad (4)$$

In the equation: a is the development factor and b is the Grey action quantity. The parameter vectors $\hat{a} = [a, b]^T$can be determined by the least squares method.

By solving the differential equation, it can be seen that:

$$\hat{x}^{(1)}(k+1) = [x^{(0)}(1) - \frac{b}{a}]e^{-ak} + \frac{b}{a} \quad (5)$$

A cumulative reduced sequence is performed on the model data:

$$\hat{x}^{(0)}(k+1) = \hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k) \quad (6)$$

From this, the grey prediction model GM (1,1) is obtained.

2.3 Applications of Energy Consumption Prediction Model

Since the "12th Five-Year Plan" period, Jiangsu Province has adopted policies to accelerate the development of non-fossil energy and issued a series of documents emphasizing the development of renewable energy. Due to this, the energy consumption during this period is not representative. For this study, the total energy consumption of Jiangsu Province from 2016 to 2022 is obtained from the "Jiangsu Statistical Yearbook - 2017-2023", published by the Jiangsu Provincial Bureau of Statistics, and is measured in 10,000 tons of standard coal.The total energy consumption of Jiangsu Province from 2016 to 2022 is presented in Table 1.

Table 1 Total Energy Consumption in Jiangsu Province from 2016 to 2022

Year	Total Energy Consumption
2016	31209.71
2017	31602.09
2018	31635.20
2019	32525.97
2020	32672.49
2021	34679.94
2022	35823.95

(1)Building the original sequence from the data in Table 1, $x^{(0)}=(x^{(0)}(1), (x^{(0)}(2), \cdots, (x^{(0)}(n))=(31209.71,31602.09,31635.20,32525.97,32672.49,34679.94,35823.95)$,1-AGO for $x^{(0)}$,generate new sequence $x^{(1)}$: $x^{(1)}=(x^{(1)}(1), x^{(1)}(2), \cdots, x^{(1)}(n))=(31209.71,62811.8,94447, 126972.97,159645.46,194325.4,230149.35)$.

(2)Exponential regularity test.A quasi-smoothness test is performed on $x^{(0)}$:

$$\rho(k) = \frac{x^{(0)}(k)}{x^{(1)}(k-1)} \in [0,0.5] \quad (2)$$

(3)Calculate the parameter vector $\hat{a} = [a, b]^T$ by the least squares method:

$$\hat{a} = (B^T, B)^{-1} B^T Y \quad (8)$$

The calculation gives a=-0.026，b=29763.122.

(4)Determine the forecasting model for energy consumption:

$$\hat{x}^{(1)}(k+1) = [x^{(0)}(1) - \frac{b}{a}]e^{-ak} + \frac{b}{a} = 2407793.325e^{0.013k} - 2376583.615 \quad (9)$$

$$\hat{x}^{(0)}(k+1) = \hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k) \quad (6)$$

Applying the prediction model to the total energy consumption of Jiangsu Province from 2016 to 2020, the corresponding simulated values, absolute errors, relative errors and average relative errors can be obtained, as shown in Table 2.

Table 2 Simulation effect of the prediction model for total energy consumption in Jiangsu Province from 2016 to 2022

Serial Number	Year	Real Value $x^{(0)}(k)$	Simulated Value$\hat{x}^{(0)}(k)$	Absolute Error$\varepsilon^{(0)}(k)$	Relative Error β_k
1	2016	31209.71	31209.71	0	0
2	2017	31602.09	30998.21	603.87	1.911%
3	2018	31635.20	31830.05	-194.850	0.616%
4	2019	32525.97	32684.21	-158.23	0.486%
5	2020	32672.49	33561.28	-888.79	2.720%
6	2021	34679.94	34461.90	218.04	0.629%
7	2022	35823.95	35386.68	437.26	1.221%
Average Relative Error $\bar{\beta}$					1.264%

A posteriori difference test is carried out using the data obtained above. Through calculation, it can be obtained that the average relative error $\bar{\beta}$=1.264%, the precision level of the first grade; small probability error P=1, the precision level of the first grade. It can be seen that the established GM(1,1) prediction model has high accuracy and good data fitting effect, so it can be used to predict the total energy consumption in Jiangsu Province from 2023 to 2027.

(5) The above model is used to predict the total energy consumption in Jiangsu Province from 2023 to 2027, and the results are shown in Table 3, measured in 10,000 tons of standard coal. Based on the forecast results in Table 3, it can be inferred that the total energy consumption of Jiangsu Province from 2023 to 2027 is expected to continue to rise, reaching an estimated 40396.43 tons of standard coal in 2027. Additionally, the average annual growth rate is anticipated to increase slightly from 1.18% to 2.68%.

Table 3 Prediction of Total Energy Consumption in Jiangsu Province from 2023 to 2027

Year	2023	2024	2025	2026	2027
Total Energy Consumption	36336.28	37311.36	38312.61	39340.72	40396.43

3. Grey Relation Analysis of Total Energy Consumption and its Influencing Factors in Jiangsu Province

3.1 Grey Relation Analysis Fundament

Grey relation analysis is a grey system analysis method proposed by Professor Deng Julong in 1982(Deng Julong, 2002)[8].The grey relation analysis model performs a quantitative statistical study by analysing the degree of geometric similarity of curve changes between multiple factors, and is suitable for dynamic comparative analysis of factor change trends.

3.2 Grey Relation Analysis Modeling Process

(1)Let the sequence of system behaviour $X_0=(X_0(1), X_0(2), \cdots, X_0(n))$, $X_1=(X_1(1), X_1(2), \cdots, X_1(n))$, ..., $X_m=(X_m(1), X_m(2), \cdots, X_m(n))$.Find the initial value image of each sequence:

$$X_I' = \frac{X_i}{x_i(1)} = (x_i'(1), x_i'(2), \dots, x_i'(n), i = 0,1,2,\dots,m \quad (10)$$

(2)Find the absolute value sequence of the difference between the corresponding components of the initial value image of X_0 and X_i:

$$\Delta_i(k) = |x_0'(k) - x_i'(k)|, \Delta_i = (\Delta_i(1), \Delta_i(2), \dots, \Delta_i(n)), i = 1,2,\dots,n \quad (11)$$

(3)Find $\Delta_i(k) = |x_0'(k) - x_i'(k)|$, k=1,2,...,n; i=1,2,...,m the maximum and minimum values:

$$M = \max_i \max_k \Delta_i(k), m = \min_i \min_k \Delta_i(k) \quad (12)$$

(4)Calculate the relation coefficient:

$$\gamma_{0i}(k) = \frac{m+\xi M}{\Delta_i(k)+\xi M}, \xi \in (0,1), k = 1,2,\dots,n; i = 1,2,\dots,m \quad (13)$$

(5)The average value of the relation coefficient can be obtained, which is the Deng's correlation degree value:

$$\gamma_{0i} = \frac{1}{n}\sum_{k=1}^{n}\gamma_{0i}(k), \ i = 1,2,\dots,m \quad (14)$$

3.3 Grey Relation Analysis Process of Total Energy Consumption and its Influencing Factors in Jiangsu Province

Domestic and foreign scholars have been studying the factors that affect total energy consumption. Hondroyiannis et al [9] found, after studying the relationship between energy consumption and GDP (Gross Domestic Product), that there is a bidirectional causal relationship between GDP (Gross Domestic Product) and energy consumption (Hondroyiannis et al., 2002). Li Jinkai [10] also observed a unidirectional or bidirectional causal relationship between energy consumption and economic growth (Li Jinkai, 2005). On the other hand, Lin Boqiang [11] argued that the increase in electricity consumption is the cause of economic growth through cointegration analysis (Lin Boqiang, 2003), while Qu Dewei et al [12] claimed that the development of electricity will directly affect the national standard of living (Qu Dewei and Sun Lin, 2007). Therefore, in this study, the four elements of GDP (Gross Domestic Product), industrial output value, total population, per capita disposable income of residents, and total energy consumption in Jiangsu Province from 2016 to 2020 were selected for grey relation analysis when selecting correlation factors. The data were obtained from the "Jiangsu Statistical Yearbook—2016-2021" published by the Jiangsu Provincial Bureau of Statistics, and the specific values are shown in Table 4.

Table 4 GDP(Gross Domestic Product), industrial output value, total population, and per capita disposable income of residents data of Jiangsu Province from 2016 to 2020

	GDP（billion yuan）	Industrial Output Value（billion yuan）	Total Population（ten thousand people）	Per Capita Disposable Income of Residents（yuan）
2016	77350.9	30291.36	8381.47	32070
2017	85869.8	33782.61	8423.50	35024
2018	93207.6	36113.22	8446.19	38096
2019	98656.8	37225.68	8469.09	41400
2020	102807.7	37744.85	8477.26	43390

For grey relation analysis, we selected the GDP (Gross Domestic Product), industrial output value, total population, and per capita disposable income of Jiangsu Province from 2016 to 2020. We then calculated the grey relation between these four factors and the total energy consumption. We designated GDP (Gross Domestic Product), industrial output value, total population, and per

capita disposable income as X_1, X_2, X_3, and X_4,respectively, and the total energy consumption in Jiangsu Province as X0. After calculating the grey relation degree, we obtained the grey relation degree between each of the four factors and the total energy consumption, which is presented in Table 5.

Table 5 Grey relation between total energy consumption and GDP(Gross Domestic Product), industrial output value, total population, and per capita disposable income of residents

Factors	GDP	Industrial Output Value	Total Population	Per Capita Disposable Income of Residents
Grey Relation	0.5606	0.5890	0.9112	0.5680

3.4 Analysis of Grey Relation Results

Through the results of grey relation analysis of total energy consumption with GDP (Gross Domestic Product), industrial output value, total population, and per capita disposable income of residents, it can be found that economic growth, total population, and other factors in Jiangsu Province have a certain relationship with the total energy consumption. Among them, the total population has the largest correlation with the total energy consumption, and the correlation between industrial output value, per capita disposable income of residents, and GDP (Gross Domestic Product) with energy consumption is the second largest, with no significant difference in correlation between the three. Total population growth is an unavoidable trend, especially as the country is now implementing policies to encourage childbirth. Therefore, it is necessary to strictly control energy consumption and reform the energy consumption structure, focusing on the development of clean energy, increasing the proportion of renewable energy in total energy consumption, reducing the proportion of energy sources such as crude coal and crude oil, and reducing carbon emissions. At the same time, it is necessary to raise residents' awareness of environmental protection. The increase in per capita disposable income indicates an improvement in people's living standards, advocating the use of low-carbon and clean energy in their lives, adopting a green way of travelling and so on, guiding residents' consumption patterns and controlling the consumption of energy.

4. Conclusions

Based on the total energy consumption data of Jiangsu Province from 2016 to 2022, this article applies the GM (1,1) to establish a prediction model for the total energy consumption in Jiangsu Province. After testing, the average relative error accuracy is at level one and the small probability

error accuracy level is at level one. The overall accuracy of the model is high, and it can accurately predict the total energy consumption in Jiangsu Province in the next five years. It is predicted that the total energy consumption of Jiangsu Province will reach 403.96 million tons of standard coal in 2027, and the average annual growth rate is still growing, and energy consumption will continue to rise.

A grey relation analysis of total energy consumption with GDP (Gross Domestic Product), industrial output value, total population, and disposable income per capita in Jiangsu Province was also carried out, and it was found that the grey relation between total population and total energy consumption was the highest. Providing recommendations based on the results of the grey correlation analysis : Continued population growth is unavoidable, so it is necessary to control energy consumption, choose clean and environmentally friendly renewable energy sources, and at the same time cultivate environmental awareness among the population and implement the concept of low-carbon living.

In previous research, the majority of studies only established a single grey prediction model or performed grey relation analysis. However, this paper goes beyond not only establishing an energy consumption prediction model but also analyzing its influencing factors. This approach enables a more scientific study of the energy consumption trend in Jiangsu Province, providing more reasonable and effective suggestions for the province.

Based on the energy consumption prediction and grey relation analysis results in Jiangsu Province, the following suggestions are proposed.

1.To continue to carry out supply-side structural reforms in Jiangsu Province. This will involve reducing investment in high energy-consuming industries and effectively curbing industrial energy consumption. In 2016, the proportion of investment in the six high energy-consuming industries in industrial investment decreased by 4.8% compared to 2012. As a result of this decline in investment, the growth rate of energy consumption in high energy-consuming industries also slowed down. Therefore, implementing supply-side structural reforms can effectively reduce the growth rate of energy consumption.

2.Vigorously develop clean energy and increase the proportion of clean energy consumption. With the promotion of national policies and growing social environmental awareness, more and more enterprises have recognized the importance of clean energy. The development of clean energy has led to a low-carbon trend in the energy consumption structure, gradually reducing the proportion of coal and advocating low-carbon production.

3.Cultivate residents' environmental awareness. Promote the concept of green and low-carbon living, guide residents to adopt green consumption, vigorously promote environmental protection

products, and save energy and control energy consumption in daily life.

4.Improve energy utilization efficiency and reduce unnecessary energy waste. This requires conserving the use of energy, adhering to strong energy-saving and emission reduction measures, strictly controlling the total amount of energy consumption, and making it a basic requirement for implementing energy consumption plans.

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