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Forecasting and Analysis of Energy Consumption in China

-- Based on Grey Forecasting Model

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Abstract: Energy is essential to the development of an economy and society. In recent years, China's rapid economic development has created the "China Miracle", but it has also led to a sharp increase in energy consumption in China. To ensure the achievement of the ambitious goal of reaching the carbon peak by 2030, it is of great significance to study the total energy consumption in China in order to promote the national energy conservation and emission reduction actions. This paper constructs models GM(1,1), DGM(1,1), and gray Verhulst model based on the original data of China's total energy consumption from 2001 to 2020, and constructs a combined forecasting model by the least squares method to make an economic forecast of China's energy consumption in the next five years. It provides a theoretical basis for making a reasonable energy planning.

Keywords: Total energy consumption, GM(1,1), DGM(1,1), Grey Verhulst model.

1. Introduction and Literature Review

With the rapid development of the global economy, the global ecological and environmental problems are also facing great challenges, and many environmental problems such as atmospheric pollution and global warming are becoming more and more serious. In response to global warming, one of the main solutions is to control climate change, and the key to control climate change is to limit the emission of greenhouse gases. On the one hand, the reduction of greenhouse gas emissions is controlled from the source, that is, the corresponding energy substitution and conservation, and on the other hand, it is controlled from the terminal, and the gases to be emitted are purified and treated. At present, energy saving and consumption reduction is also the focus of close attention of all sectors of society.

Energy is not only an important basis for human survival and development, but also an important basis for the normal operation and development of society and economy. It is also an important foundation for the normal operation and development of society and economy. It is also the key to maintaining world peace and consolidating national security. According to a study, China's economy is the second largest in the world, and its consumption of resources and energy has been steadily increasing, from 571 million tons of standard coal in 1978 to 4.64 billion tons of standard coal in 2018, an average annual increase of 100 million tons of standard coal in 40 years. For a long time, energy consumption is "more coal, poor oil and less gas", with coal consumption in the main position. 1978-2018, the proportion of coal consumption basically fluctuated around 70 %, and after 2012, when the low-carbon economy prevailed, the proportion of coal consumption began to show a decreasing trend and reached the lowest in 2018. After 2012, the share of coal consumption started to decline, and reached the lowest level of 59% in 2018. Oil consumption is in an inverted U-shape with the year 2000 as the cut-off point, with a share of 18.9 % in 2018. The share of natural gas and nuclear, hydroelectric, and wind power have all increased year by year since 2005. Due to the finite nature of resources and energy, the contradiction caused by endless exploitation and utilization is becoming more and more prominent, and the economical use of energy and the development of alternative clean energy sources have become one of the focuses of widespread attention at home and abroad. China's "Action Plan for Carbon Peaking by 2030" clearly states that "by 2030, the proportion of non-fossil energy consumption will reach about 25% to achieve the goal of carbon peaking." Therefore, how to control energy consumption scientifically and reasonably is not only of great importance to China's society, economy and ecology, but also an important measure to fully implement the great cause of ecological civilization construction.

In recent years, scholars at home and abroad have conducted a large number of prediction studies on the issue of energy consumption. Claudia et al. used competing models to make scientific predictions of energy consumption in China, the United States, India, and Europe [1].Xia et al. studied the factors affecting the structure of energy consumption in China and constructed a combinatorial model to predict energy consumption in their article[2].Jana et al. proposed a model based on the maximum Jana et al. proposed a particle based on maximum overlap discrete wavelet transform and long and short term memory network to predict energy consumption [3]; besides predicting macro energy consumption, many scholars also predict data related to non-renewable and renewable energy consumption. Yu et al. proposed a prediction model for oil consumption in the context of big data based on search results of Google engine to predict worldwide oil consumption [4].Qiao et al. proposed a new hybrid forecasting model to predict short-term natural gas consumption with an adaptive filter and an improved whale optimization algorithm [5].

In addition, based on different scenarios and policy environments, Zhou Di et al. used scenario analysis methods to predict the energy consumption of public buildings in China in 2020 [6]. Wan Lei [7] constructed an energy efficiency model for Yunnan Province based on IPAT. By using the energy consumption data of Yunnan Province from

1990 to 2005 and other related data, a variety of different application scenarios were set to analyze and predict the energy consumption of Yunnan Province in 2010 and 2020. Pang Jiaxing et al [8] used the decoupling index evaluation method to deeply analyze and study the direction and degree of influence of economic growth on energy consumption in Gansu Province, and on this basis, predicted the total energy consumption in Gansu Province under the set relevant scenario model. Based on the IPAT model, Zhu Yuan et al [9] set two scenarios based on different GDP growth and predicted the future peak year of carbon emissions in Shanxi Province. Nie Cong, Zhu Lujie, Huang Fang, and Gao [10,11,12,13] used different scenario analysis methods to analyze the future energy consumption in Jiangsu Province, the electricity consumption in residential buildings in Quanzhou, the energy demand in Shanghai, and the energy consumption and pollutant emissions in urban passenger transportation in Beijing, and predicted the energy consumption under various different scenarios in a certain period of time in the future. Zhu et al [14] simulated, analyzed and tested the manufacturing energy consumption in Jiangsu Province from 1999 to 2008, and predicted the manufacturing energy consumption in Jiangsu Province from 2009 to 2015 using the established gray GM(1,1) prediction model. Gao Hong et al [15] predicted the electricity consumption of manufacturing industries in China from 2011-2015 by establishing a gray GM(1,1) prediction model. Yang Haochang et al [16] predicted the total output value and development trend of manufacturing industry in Jiangsu Province by establishing a gray GM(1,1) prediction model based on the development of manufacturing industry in Jiangsu Province from 2004-2016. Caihong Zhou et al [17] established a gray GM(1,1) prediction model based on the manufacturing industries of China, the United States, Germany, Japan, Korea and the United Kingdom to predict and compare the development trend of manufacturing industries in six countries in 2020. Cheng Wenrong et al [18] established a gray GM(1,1) prediction model based on the weakened energy consumption data of high energy-consuming and high-polluting industries, chemical raw materials and chemical products manufacturing industries in Nanjing from 2002 to 2012, and predicted the energy consumption and major energy consumption of chemical raw materials and chemical products manufacturing industries in Nanjing from 2013 to 2020. Gong Zejun et al [19] selected eight energy sources of China's manufacturing industry from 2005-2015, and predicted the energy consumption of China's manufacturing industry from 2016-2020 by establishing a gray GM(1,1) prediction model based on the consumption data of these eight energy sources.

2. Data Sources and Current Situation Analysis

The original data in this paper are listed as the total energy consumption in China for 20 years from 2001-2020. (All data in this paper are from the National Bureau of Statistics, unit: billion tons of standard coal).

From the graph, we can see that China's total energy consumption from 155,547 million tons of standard coal in 2001 to 498,000 million tons of standard coal in 2020, a total growth of 342,453 million tons of standard coal, with an average annual growth rate of 11.6%, energy consumption growth is obvious and remains relatively stable, based on this trend, it can be intuitively concluded that total energy consumption in the coming period will remain stable Growth.

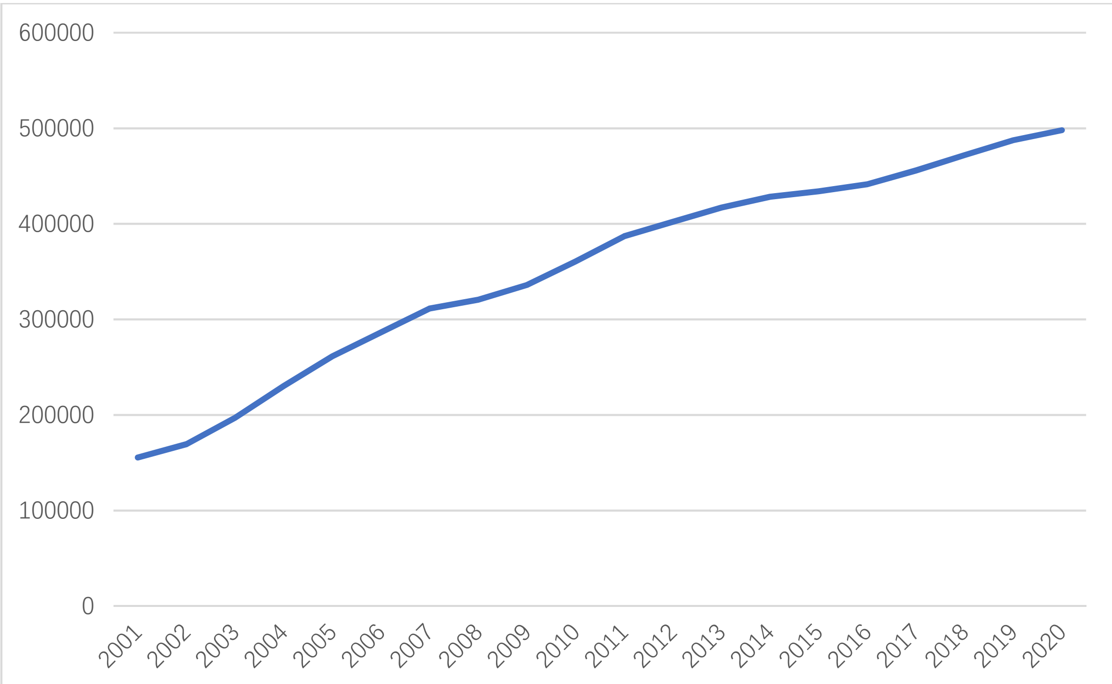

Figure 1. Total energy consumption in China from 2001 to 2020 (billion tons of standard coal)

3. Model Construction and Forecast

3.1. Gray Forecasting

Gray forecasting is a method to forecast systems with uncertainties. It generally uses time series data to forecast by building GM(1,1) model.GM(1,1) model is a basic gray forecasting model and one of the powerful tools in gray forecasting. The steps of gray forecasting in GM(1,1) model are as follows.

Let the non-negative sequence of incomplete information be, and generate the 1-AGO (1-Accumulating Generation Operational) sequence. 1-AGO sequence is similar to the accumulation fold in Pareto chart. That is $X^{(0)} = \left\{ x^{(0)}(1), x^{(0)}(2), ..., x^{(0)}(n) \right\}$, let the original sequence be $x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i), k = 1, 2, ..., n$,generate the new sequence as $X^{(1)} = \left\{ x^{(1)}(1), x^{(1)}(2), ..., x^{(1)}(n) \right\}$,where the knowledge of calculus is used to construct the gray differential equation of GM(1,1) model, where a is the development coefficient and b is the amount of gray action. The mean value form of GM(1,1) model Z(1), $x^{(0)}(k) + az^{(1)}(k) = b$, $z^{(1)}(k) = 0.5(x^{(1)}(k) + x^{(1)}(k-1))$ is obtained by the equation to construct the gray prediction matrix: $Y_n = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \cdots \\ x^{(0)}(n) \end{bmatrix}$,

$\theta = \begin{bmatrix} a \\ b \end{bmatrix}^T$, $B_n = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \cdots & \cdots \\ -z^{(1)}(n) & 1 \end{bmatrix}$,such that $Y_n = B_n \theta$.

Construct the function by least squares method and find the estimated value: $J(\hat{\theta}_n) = (Y - B_n \hat{\theta}_n)^T (Y - B_n \hat{\theta}_n)$, $\hat{\theta}_n = (B_n^T B_n)^{-1} B_n^T Y_n$,The whitened differential equation of GM(1,1) is: $\frac{dx^{(1)}}{dt} + aX^{(1)} = b$,,The gray prediction model $\hat{x}^{(0)}(k) = \hat{x}^{(1)}(k) - \hat{x}^{(1)}(k-1) = (1-e^{a})(x^{(0)}(1) - \frac{b}{a})e^{-a(k-1)}, k = 1, 2, ..., n$ is obtained by $x^{(0)}(k) + az^{(1)}(k) = b$ obtaining the response function and calculating $\hat{x}^{(1)}(k) = (x^{(0)}(1) - \frac{b}{a})e^{-a(k-1)} + \frac{b}{a}$.

3.2. DGM(1,1) Model

The modeling mechanism of DGM(1,1) model is basically consistent with the gray prediction model, and is a unique form belonging to the gray prediction model. It can be seen as an exact form of GM(1,1) model, which can be substituted for each other when it is smaller, and its modeling process is as follows.

First, let be a set of non-negative series $X^{(0)} = \left\{ X^{(0)}(1), X^{(0)}(2), ..., X^{(0)}(n) \right\}$,. Second, a cumulative sequence $X^{(1)} = \left\{ X^{(1)}(1), X^{(1)}(2), ..., X^{(1)}(n) \right\}$ is computed by Excel, where $X^{(1)}(k) = \sum_{i=1}^{k} X^{(0)}(i), (k = 1, 2, ..., n)$. Next, take the least squares method to calculate the relevant parameter values, if $\hat{\beta} = (\beta_1, \beta_2)^T$ is the parameter column,and $Y = \begin{bmatrix} x^{(1)}(2) \\ x^{(1)}(3) \\ \cdots \\ x^{(1)}(n) \end{bmatrix}, B = \begin{bmatrix} x^{(1)}(1) & 1 \\ x^{(1)}(2) & 1 \\ \cdots & \cdots \\ x^{(1)}(n-1) & 1 \end{bmatrix}$,then the least squares estimated parameter column of the discrete gray prediction model $\hat{\beta} = (\beta_1, \beta_2)^T = (B^H B)^{-1} B^T Y$ is satisfied. Then $X^{(1)}(1) = X^{(0)}(1)$, take, then the recursive function is $\hat{X}^{(1)}(k+1) = \beta_1^k X^{(0)}(1) + \frac{1-\beta_1^k}{1-\beta_1} * \beta_2$ or $\hat{X}^{(1)}(k+1) = \beta_1^k (X^{(0)}(1) - \frac{\beta_2}{1-\beta_1}) + \frac{\beta_2}{1-\beta_1}$. Finally, the reduction value $\hat{X}^{(0)}(k+1) = \hat{X}^{(1)}(k+1) - \hat{X}^{(1)}(k)$ is found.

3.3. Gray Verhulst model

The basic idea of the gray Verhulst model is that the number of biological individuals grows exponentially. Restricted by the surrounding environment, the growth rate gradually slows down and finally tends to a fixed value. The gray Vehulst model is mainly used to describe processes with a saturation state, i.e. "S" processes. The modeling process of the model is as follows.

In the first step, the original data series $X^{(0)} = \left\{ x^{(0)}(1), x^{(0)}(2) ... x^{(0)}(n) \right\}$ is created with a set of time series, and the data is correlated to generate the series, such that $X^{(1)}(k) = \sum_{t=1}^{k} x^{(0)}(t)$, the newly generated series is $X^{(1)} = \left\{ x^{(0)}(1), \sum_{t=1}^{2} x^{(0)}(t) ... \sum_{t=1}^{n} x^{(0)}(t) \right\}$. The second step is to generate the immediate mean sequence $X^{(1)} = \left\{ x^{(0)}(1), \sum_{t=1}^{2} x^{(0)}(t) ... \sum_{t=1}^{n} x^{(0)}(t) \right\}$, where $k = 2, 3, ..., n$. In the third step, the Verhulst model is established: $X^{(0)} + aZ^{(1)} = b(Z^{(1)})^2$,is the parameter to be determined, the differential equation equation of this function is $\frac{dx^1(t)}{dt} + ax^1(t) = b(x^1)^2$, and the solution is $x^{(1)}(t) = \frac{ax_0^{(1)}}{bx_0^{(1)} + (a - bx_0^{(1)})e^{at}}$. Finally, the Verhulst prediction model: $x^{(0)}(k+1) = x^{(1)}(k+1) - x^{(1)}(k)$ is obtained, and the parameters to be determined are estimated by least squares: $[a, b] = (B^T B)^{-1} B^T Y_n$.

3.4. Combined Forecasting Model

Combined forecasting is also known as integrated forecasting or compound forecasting in China. It is to forecast the same problem by using more than two different forecasting methods. The purpose of combination is to combine the characteristics of various models to consider a problem in as many directions as possible and improve its forecasting accuracy. In this paper, the least squares method is used to combine the above three gray prediction models. Using the predicted value of each model as the independent variable and the actual value as the dependent variable, the multiple linear regression equation is constructed as follows.

$$Y_{real} = \alpha X_{GM(1,1)} + \beta X_{DGM(1,1)} + \gamma X_{Verhulst} + \varepsilon$$

where Y_{real} is the actual value, $X_{GM(1,1)}$ is the predicted value of the GM(1,1) model, $X_{DGM(1,1)}$ is the predicted value of the DGM(1,1) model, $X_{Verhulst}$ is the predicted value of the gray Verhulst model, and α、β、γ、ε is the coefficient to be determined.

Table 1. Forecast values of total energy consumption for GM(1,1), DGM(1,1) and grey Verhulst models (in million tons of standard coal)

year	Actual value	GM (1, 1)	DGM (1, 1)	Verhulst
2001	155547	155547	155547	155547
2002	169577	234955.694	235264.27	175904.0322
2003	197083	245912.085	246214.1084	197528.8523
2004	230281	257379.3915	257673.582	220170.3226
2005	261369	269381.4384	269666.4107	243519.82
2006	286467	281943.1615	282217.4182	267226.3013
2007	311442	295090.6595	295352.5837	290916.5934
2008	320611	308851.2482	309099.0955	314218.5375
2009	336126	323253.5169	323485.4074	336784.0007
2010	360648	338327.3883	338541.2972	358308.7975
2011	387043	354104.1805	354297.9291	378547.2273
2012	402138	370616.6719	370787.9175	397320.0222
2013	416913	387899.1693	388045.3947	414515.6871
2014	428334	405987.5795	406106.0818	430086.2093
2015	434113	424919.4837	425007.3623	444038.7141

The total energy consumption from 2001 to 2015 was used as the fitted data for the combined forecasting model, and the total energy consumption from 2016 to 2020 was used as the test data for the combined forecasting model to forecast the total energy consumption from 2021 to 2025.

The predicted values of total energy consumption for each year obtained from the GM(1,1) model, DGM(1,1) model and gray Verhulst model were used as explanatory variables, and the actual values of energy consumption in China were used as the explanatory variables. Regressions were performed using relevant statistical software, and the resulting multiple linear regression equations were.

$$Y_{real} = -27.06X_{GM(1,1)} + 27.09X_{DGM(1,1)} + 0.97X_{Verhulst} + 1289.44$$

Table 2. Predicted values of total energy consumption by grey combination prediction model (unit: million tons of standard coal)

year	Actual value	GM (1, 1)	DGM (1,1)	Verhulst	Combined predicted values
2016	441492	444734.2153	444788.3598	456424.8278	458830.2861
2017	455827	465472.9421	465490.0187	467329.3444	469025.6574
2018	471925	487178.7518	487155.1891	476859.4271	477820.0937
2019	487488	509896.7409	509828.7153	485135.1414	485324.5766
2020	498000	533674.1092	533557.5291	492281.7165	491654.7326
2021		558560.2574	558390.7463	498423.6199	496925.0637
2022		584606.8898	584379.769	503680.3223	501244.816
2023		611868.1218	611578.3913	508163.515	504715.2557
2024		640400.5922	640042.9115	511975.496	507428.0782
2025		670263.5812	669832.2478	515208.4488	509464.6807

As shown in Table 2, the predicted values of total energy consumption of the GM(1,1) model, the DGM(1,1) model and the gray Verhulst model from 2021 to 2025 are substituted into the regression equation to obtain the predicted values of total energy consumption of the gray prediction model based on the least squares combination. As can be seen from Table 2, the predicted values of China's total energy consumption from 2016 to 2020 for the combined model are closer to the actual values than the GM(1,1) model and the DGM(1,1) model. However, the predicted values are not as accurate as compared to the Verhulst model. Based on the Verhulst model, it is predicted that the total energy consumption in China will reach 498,423.62 million tons of standard coal in 2021, and the predicted value of total energy consumption will exceed 500,000 million tons of standard coal by 2022, and will reach 515,208.45 million tons of standard coal by 2025. From the results, it can be seen that the growth of total energy consumption in China will show a slowing trend, which may be due to the attention of the Party and the State to environmental issues in recent years and the increased investment in renewable energy to promote industrial structure upgrading.

4. Conclusions and Suggestions

4.1. Conclusion

At present, scholars have conducted many studies and forecasts in the field of energy to obtain data for key decisions. This research paper scientifically predicts the total energy consumed in our country from 2021 to 2025 by using GM(1,1) model, DGM(1,1) model, gray Verhulst model, and combined prediction model. By comparing the predicted values of the four models with the actual values, the gray Verhulst model predicts the most accurately. The Verhulst model shows that the total energy consumption in China will reach 498,423,626,000 tons of standard coal in 2021, and the predicted value of total energy consumption will exceed 500,000,000 tons of standard coal by 2022 and reach 515,208,450 tons of standard coal by 2025. The growth trend of total energy consumption is gradually slowing down.

4.2. Recommendations

China is the world's largest developing country and one of the fastest growing economies. The economic growth and population pressure have challenged China's energy supply.

In addition to this, the deteriorating global climate has put new demands on energy consumption. Under the new social development pattern of carbon peak and carbon neutral, it is urgent to accelerate the green change of production and life style.

First, under the premise of ensuring energy security, vigorously implement renewable energy alternatives and accelerate the construction of a clean, low-carbon, safe and efficient energy system. Specifically, we should vigorously develop new energy, develop hydropower in accordance with local conditions, and reasonably regulate the consumption of oil and natural gas. Second, the implementation of conservation priority policy, improve the energy consumption intensity and the total amount of double control degree, the construction of energy-saving society. For example, the implementation of key projects to reduce energy consumption and carbon emissions, and promote energy saving and efficiency of key energy-using equipment. Third, grasp the source of resource utilization, vigorously develop the circular economy, comprehensively improve the efficiency of resource utilization, and fully reduce the synergistic effect of resource consumption and carbon emission reduction. Fourth, play the supporting and leading role of science and technology innovation, improve the science and technology innovation system, enhance innovation capacity, and accelerate the green low-carbon science and technology revolution.

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