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Forecast of Coal Consumption in China: Using Grey Model、Nonlinear Regression Model and Elasticity Coefficient Model

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Abstract

Coal energy is the main consumption of energy in China at this stage, coal consumption forecast is very important. Accurate prediction of coal consumption can help the government to make the correct energy development plan and ensure the China's economy with a steady, rapid and healthy development. Coal energy consumption and GDP, the rate of economic growth, the total primary energy demand and the ratio of coal consumption in the total primary energy consumption, based on the China statistical yearbook data, the future coal consumption is predicted according to the grey model, the nonlinear regression model and the elasticity coefficient forecasting model. The prediction results of the above three models are compared and analyzed.

Keywords

Coal consumption; Forecast; Grey model; Nonlinear regression model; Elasticity coefficient mode.

1. Introduction

As a primary energy, coal resource is a non-renewable resource. It has a high dominates status in the primary energy consumption in China1. In 2019, the ratio of coal consumption to the total primary energy consumption is 57.7%, the petroleum is 18.9%, and the clean energy is 23.4%. Because the coal consumption is far greater than petroleum and natural gas2, China is still in a Coal Age.

On the one hand, the rapid economic growth requires energy security, and coal has made a great contribution to economic growth, with the sustained and rapid economy development, and the demand for coal keeps increasing. The emerging modern coal chemical industry produces methyl alcohol, olefins, aromatic hydrocarbons, ethylene glycol and other products that are in urgent need of chemical raw materials for modernization. Natural gas is synthesized from coal and gas oil is prepared from coal, which can reduce the external dependence of oil and gas. The above situation can increase coal consumption. On the other hand, China joined the Paris Agreement in 20162, 3, to reduce carbon dioxide emissions, to improve the environment and to safeguard the blue sky, the Chinese government will regulate and control coal consumption in thermal power generation and steel, and the proportion of coal in primary energy will be reduced year by year.

In 2019, the crude oil external dependence is 70.8%, and natural gas is 43% in China. It is so high levels of energy external dependence and increasing year by year. Nonetheless, coupled with the complex and volatile international situation, how can China ensure its energy security? To achieve low-carbon and comprehensive utilization of coal energy, to increase the mutual conversion among the coal, petroleum and natural gas and then each one is replaced by coal,

solar energy, wind energy and other renewable resources when another is lack of that to reduce the external dependence of oil and natural gas. This is one of the ways to guarantee domestic energy security. The comprehensive analysis of factors affecting coal consumption and the scientific prediction of coal resource demand in China is one of great significance things for formulating the correct energy development plan, ensuring the realization of strategic goals, and building a conservation-minded society and a harmonious society.

In the past few years, many experts and scholars have done a lot of research on the field of coal consumption and have made some progress. Li et al.4 predicted China's medium and long-term coal demand with five methods. Cheng et al5. forecasted clean energy consumption in China by 2025using improved Grey model GM(1,N). Jiang et al3. analyzed coal production and consumption and forecasted of related carbon emission in China. Duan et al6. predicted coal consumption with a novel forecasting approach based on multi-kernel nonlinear multivariable grey model. Zhang et al.7 predicted of coal feeding during sintering in a rotary kiln based on statistical learning in the phase space. Jia et al.8 forecasted of coal consumption in Gansu Province based on Grey-Markov chain model. Li et al.9 forecasted coal consumption in India by 2030 using linear modified linear (MGM-ARIMA) and linear modified nonlinear (BP-ARIMA) combined models. Liu et al.10 forecasted primary energy consumption in Spanish economic sectors with a grey neural network and input-output combined forecasting model. Ma et al.11 predicted of coal consumption in Shandong province- with ARIMA model and metabolism GM (1, 1) model. Wang et al.12 forecasted when has China's coal consumption peaked and analyzed a demand-side based on hybrid prediction models.

Although many experts have done a lot of forecast work, still has a lot of work to do for a precise forecast. The relationship between the various influence factors to the coal consumption and the influence size also need to be refined. In this paper, we use three models to forecast the coal consumption in China, gray method, nonlinear regression model and elasticity coefficient mode, and we compared and analyzed the prediction results of the above three models.

2. Methodology

2.1. Data Sources

In this paper, the time series data during 1990-2019 have been selected. To guarantee the data reliability, the data source on the coal consumption in China adopted by the paper is from the Statistical Year book of China. These data will be used to take prediction to the coal consumption through gray method, nonlinear regression model and elasticity coefficient mode.

Table 1 Data Description.

Data	Unit	Years	Data Sources
Coal consumption	Mtce (Million tons of coal equivalent)	1990-2019	China Statistical Yearbook
GDP	Billion RMB	1990-2019	China Statistical Yearbook
Economic growth rate	%	1990-2019	China Statistical Yearbook
Total primary energy consumption	Mtce	1990-2019	China Statistical Yearbook
Proportion of coal energy consumption	%	1990-2019	China Statistical Yearbook

Coal consumption	Mtce	1990-2019	China Statistical Yearbook

2.2. Model Theory

2.2.1. Grey Models

Grey model is based on the theory of grey system and is a scientific method for forecasting the future development of various fields. Grey model is a quantitative relationship between the present and the future on the time axis, predicting data trend through this quantitative relationship. GM (l, 1) is the most widely used model for gray prediction. It builds a prediction model by performing inertial sequence to obtain the distribution of predicted values. Therefore, the grey model in this paper adopts the establishment of GM (1, 1) model.

Step 1:List the original data columns;

$$X^{(0)}=\left(X^{(0)}(1),\ X^{(0)}(2),\cdots,X^{(0)}(\mathrm{n})\right) \tag{1}$$

Step 2: Build a GM (1, 1) differential model;

$$\frac{dx^{(1)}}{dt}+ax^{(1)}=b \tag{2}$$

$$X^{(1)}(\mathrm{k})=\sum_{i=1}^{k}\mathrm{X}^{(0)}(i),\mathrm{k}=1,2,3\ldots,n \tag{3}$$

Step 3: Determine the sequence matrix;

$$\hat{a}=\begin{bmatrix}a\\b\end{bmatrix}=\begin{bmatrix}B^T & B\end{bmatrix}^{-1}B^TY_N$$

$$B=\begin{bmatrix}\frac{-1}{2}(X^{(1)}(1)+X^{(1)}(2)) & 1\\ \frac{-1}{2}(X^{(1)}(2)+X^{(1)}(3)) & 1\\ \cdot & \cdot\\ \cdot & \cdot\\ \cdot & \cdot\\ \frac{-1}{2}(X^{(1)}(\mathrm{n-1})+X^{(1)}(\mathrm{n})) & 1\end{bmatrix},\quad Y_N=\begin{bmatrix}X^{(0)}(2)\\X^{(0)}(3)\\ \cdot\\ \cdot\\ \cdot\\ X^{(0)}(\mathrm{n})\end{bmatrix}$$

Step 4: Obtain the prediction calculation formula;

$$\hat{X}^{(1)}(k+1)=(X^{(0)}(1)-\frac{\mathrm{b}}{\mathrm{a}})e^{-ak}+\frac{b}{a} \tag{4}$$

$$\hat{X}^{(0)}(k+1) = \hat{X}^{(1)}(k+1) - \hat{X}^{(1)}(k) \tag{5}$$

Step 5: Calculate the forecast data.

2.2.2. Nonlinear Regression Model

The nonlinear regression model is the second method adopted in this paper for coal consumption prediction. It is based on the relationship between the dependent variable and the independent variable, to analyze the coal consumption change trend, and then establishes a nonlinear model according to this trend to predict the future value of the variable, which is a quantitative prediction method. The nonlinear regression model prediction can be divided into exponential trend prediction, logarithmic trend prediction and power trend prediction according to the different of nonlinear equation.

According to the official statistical data, to match the trend of coal consumption and the time to obtain nonlinear regression equations and establish a nonlinear model. After that, to calculate the value of coal consumption for a period of time in the future using nonlinear regression equations in the nonlinear model, and then we obtain the prediction results. The correlation coefficient R value in the fitting function is a very important parameter, which represents the correlation between coal consumption and time. The larger the R value, the better the trend fitting degree is and the more reliable the prediction result is.

2.2.3. Elasticity Coefficient Model

The elasticity coefficient of energy consumption is an indicator that reflects the proportional relationship between the growth rate of energy consumption and the growth rate of national economy. The elasticity of coal resource consumption is the size of changes in coal resource consumption caused by the change in national economic growth. In other words, elasticity of coal resource consumption is the percentage change of coal consumption caused by every 1% of economic growth. The consumption elasticity method is based on this elasticity coefficient to predict the coal consumption. Therefore, according to the size of the economic growth rate and the size of the consumption elasticity coefficient, the coal consumption is obtained.

$$Y_t = Y_{t-1} * (\varepsilon * \eta + 1) \tag{6}$$

$$\text{The elasticity coefficient} = \frac{\text{Annual average growth rate of coal consumption}}{\text{National economic growth rate}}$$

Y_t is the coal consumption at t time, Y_{t-1} is the coal consumption at t-1 time, ε is the economic growth rate, and η is the consumption elasticity coefficient.

3. Results and Discussion

3.1. Grey Model Verification

According to the grey model, the data of the coal consumption from the Statistical Year book of China is taken to establish the coal consumption matrix from 2000 to 2014. Through matrix calculation, the values of two parameters a and b are obtained to establish the functional relationship of coal consumption.

Table 2 Error Comparison

Year	Absolute Error	Year	Absolute Error	Year	Absolute Error
2001	0.134	2006	0.141	2011	5.60
2002	0.014	2007	0.263	2012	12.47

2003	0.027	2008	0.53	2013	34.67
2004	0.047	2009	1.11	2014	110.05
2005	0.076	2010	2.21		

As can be seen from Table 2, the absolute error from 2001 to 2011 was still relatively small, but by 2012, the error was 12.47%, more than 10%; in 2013, the error was even larger, 34.67%; in 2014, the absolute error had reached 110.05%, and the prediction was no longer accurate.

3.2. Nonlinear Regression Model Verification

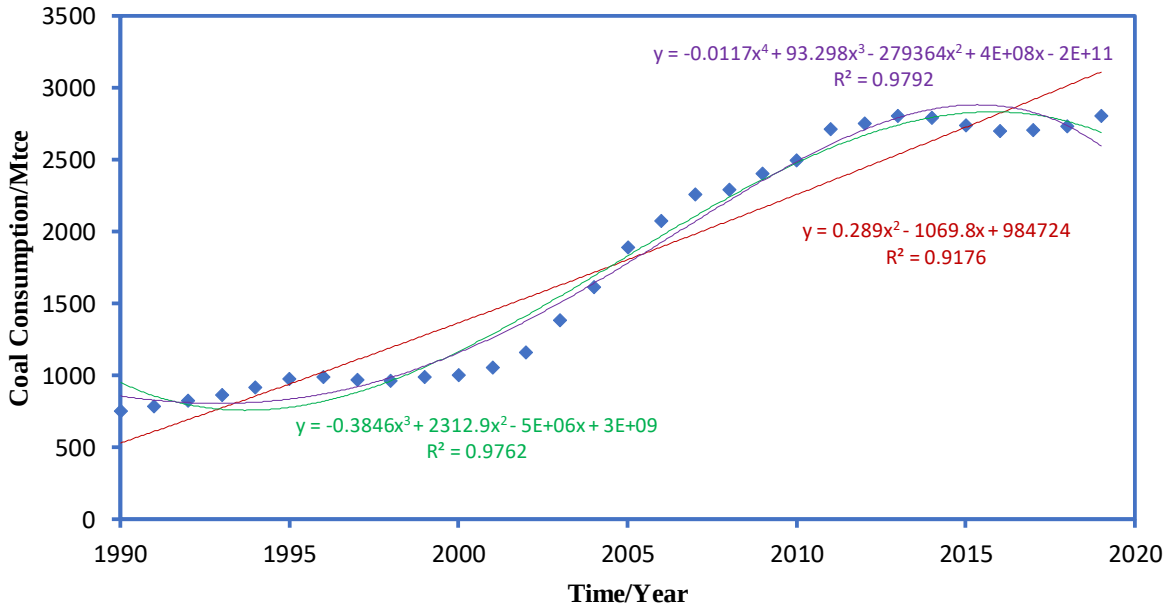

Figure1. The curve fitting of coal consumption

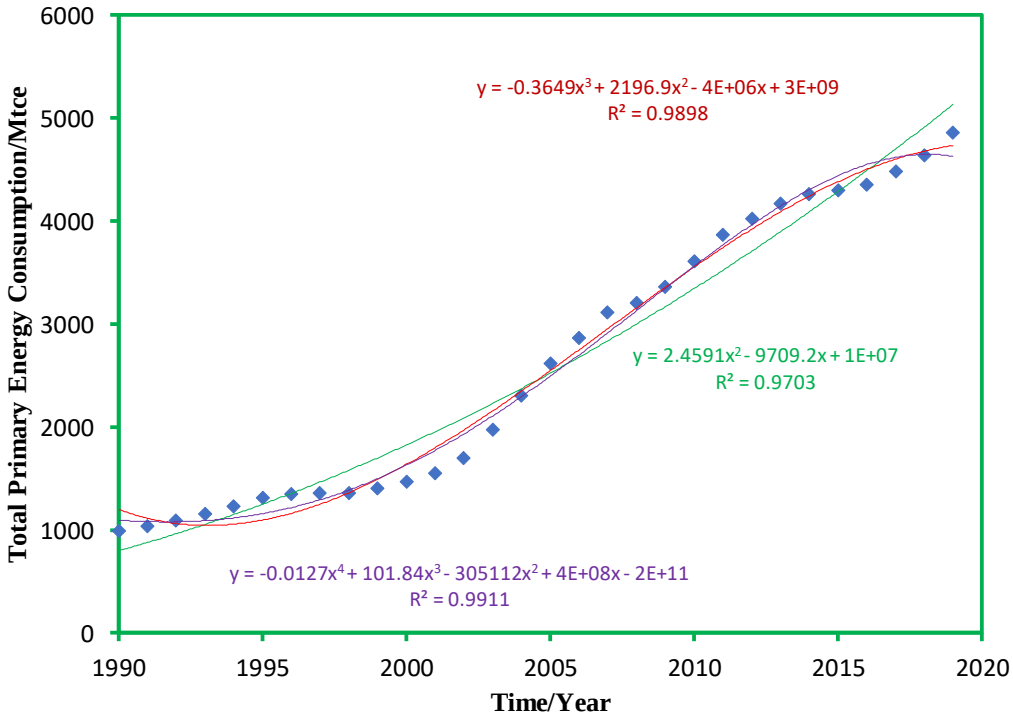

Figure2. The curve fitting of total primary energy consumption

According to the nonlinear regression model, we analyzed the data from 1990 to 2019, fitted the quadratic, cubic and quartic equation function respectively. In the meantime we found that

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the value $R_2 < R_3 < R_4$. The higher the value of R, the more closely between the curve and the real data.

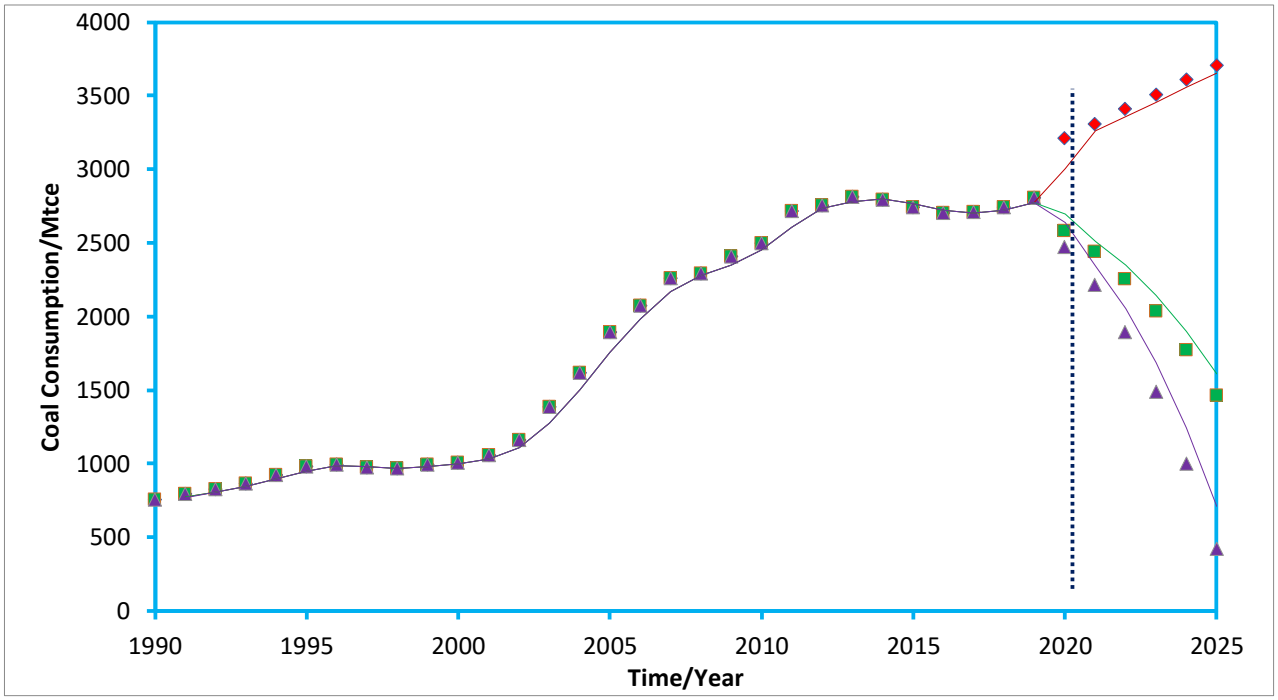

Figure3. Chart of coal consumption in the next five years in China

According to the nonlinear regression model, we predict the change trend of coal consumption in the future five years. From Figure 3, we can see the quadratic function curve is still an upward tendency, the cubic function curve has tended to decline gradually, obviously declined in the quartic function curve. Relate to the current China economic growth, energy policies and environmental protection requirements, the nowadays rapid economic growth in China requires energy support thus cause the primary energy consumption will be continue to rise. However, the proportion of coal in primary energy consumption will not increase significantly. Therefore, the cubic function is more in line with the actual situation of coal consumption.

3.3. Elasticity Coefficient Model Verification

The most important factors in elasticity coefficient prediction model are the elasticity coefficient and economic growth rate, which are the main factors affecting the prediction results. Table 3 shows the values of these two parameters.

Table 3 List of Economic Growth Rate and Elasticity Coefficient

Year	Rate of economic growth/%	Elastic Coefficient	Year	Rate of economic growth/%	Elastic Coefficient
2020	5.00	0.3	2031	3.00	0.2
2021	4.00	0.3	2032	3.00	0.1
2022	4.00	0.3	2033	3.00	0
2023	4.00	0.3	2034	3.00	0
2024	4.00	0.3	2035	3.00	-0.1
2025	4.00	0.3	2036	2.00	-0.1
2026	4.00	0.2	2037	2.00	-0.2
2027	4.00	0.2	2038	2.00	-0.2
2028	4.00	0.2	2039	2.00	-0.3

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2029	4.00	0.2	2040	2.00	-0.3
2030	3.00	0.2			

We don't believe that the Chinese economy can keep the growth rate of more than 5% all the time. In the next few years, China's economic growth rate will slow down. Therefore, we set the economic growth rate to be between 2% and 5%, and the elasticity coefficient is (-0.3, 0.3). According to the economic growth rate and elasticity coefficient in Table 3, using elasticity coefficient model to calculate the coal consumption in the next 20 years, and drawing in Figure 4.

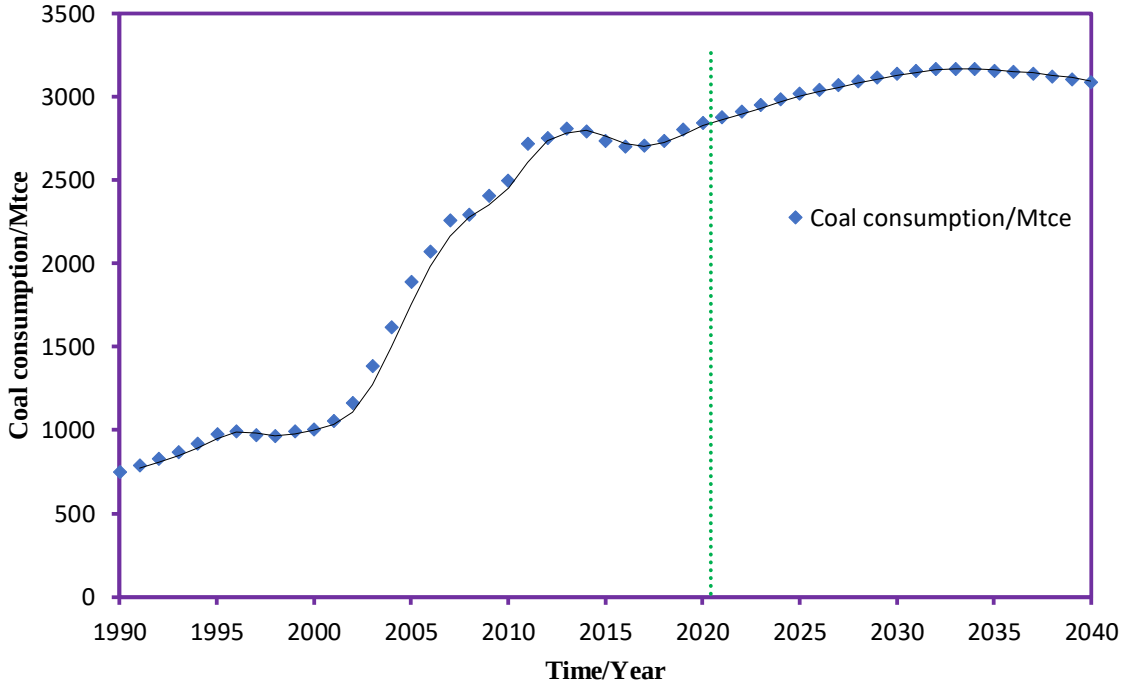

Figure 4 Chart of coal consumption under Elasticity Coefficient Model

From Figure 4, we can see a general trend of coal consumption. In the next 20 years, coal consumption will increase slightly, but not much. In the long run, coal consumption will fall back to a reasonable range.

4. Conclusion

Through three prediction models, the variation trend of coal consumption is predicted, among which the grey model has a large error and the elasticity coefficient model results is good, but the GDP growth rate and the elastic coefficient need to be determined accurately.

Nonlinear regression model can directly fit the data. Different fitting equations can get different fitting results. The closer R value is to 1, the better fitting curve can be corresponding to the actual point. We did a comparative analysis of the quadratic, cubic and quartic equation function and came to the conclusion that the cubic function is more in line with the actual situation of coal consumption.

The coal consumption has a great relationship with the market demand, crude oil price fluctuations, economic growth, renewable energy supplementary capabilities, government policies factors and environmental indicators. To establish a comprehensive multi-factor dynamic prediction model is forecast direction in the future.

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