Forecasting of Fujian Province's Energy Consumption in 2025 Using Gm (1, 1)

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Abstract: This paper analyzes the current situation of energy consumption in Fujian Province by using the data of total and composition of energy consumption of Fujian Province from 2006 to 2019 and the data of comprehensive energy balance sheet of Fujian Province from 2009 to 2019. And then, the GM (1,1) prediction method was used to construct the energy consumption prediction model for forecasting the energy consumption of Fujian Province in 2025. The results show that under the current economic development trend, the energy consumption of Fujian province will reach to 18389.191 ×104 tons of SCE in 2025.

1. Introduction

In recent years, the high energy consumption and high emission industries in Fujian Province is gradually reducing due to the optimization of industrial structure. However, with the speeding up of industrialization and urbanization, and the growing energy consumption demand, the problems about the resources and environment are still a key factor to restrict the development of social economy. So the energy conservation and emissions reduction is still a long way to go. By 2019, Fujian's total energy consumption was as high as 137.1831 million tons of standard coal. By 2018, its sulfur dioxide emissions were 121,900 tons, wastewater emissions were 3.261 billion tons, industrial solid waste production was 61.176 million tons, and industrial waste gas emissions were 1985.487 billion cubic meters. Therefore, we must not slacken our efforts to promote energy conservation and emission reduction.On the basis of analyzing the current situation of energy consumption in fujian province, this paper expounds the basic theory of GM (1,1) and predicts the energy consumption of Fujian Province in 2025 by applying GM (1,1).

2. Energy Consumption Status Analysis of Fujian Province

As shown in Figure 1, Fujian's total energy consumption showed a trend of annual increase, and its total energy consumption increased from 45.278 million tons of standard coal in 2004 to 137.1831 million tons of standard coal in 2019, with an average annual growth rate of 7.83%. In addition, in can be seen from Figure 1 that coal and oil account for the majority in the energy consumption structure. Although they accounted for less than 70% of the total energy consumption in 2016 and 2017, which declined somewhat, they accounted for more than 70%-89% in other years. Industrial energy consumption accounts for the majority of the terminal energy consumption from 2009 to 2019, which is much higher than other industries. Although it fell back in 2016, the overall trend is on the rise. In particular, it reached 90,501,400 tons of standard coal in 2019, accounting for 65.975% of the total energy consumption. It can be seen that Fujian province still relies on the secondary industry to stimulate economic growth. However, this traditional development model will lead to serious environmental degradation, further aggravating the contradiction between resource supply and demand and environmental constraint [1].

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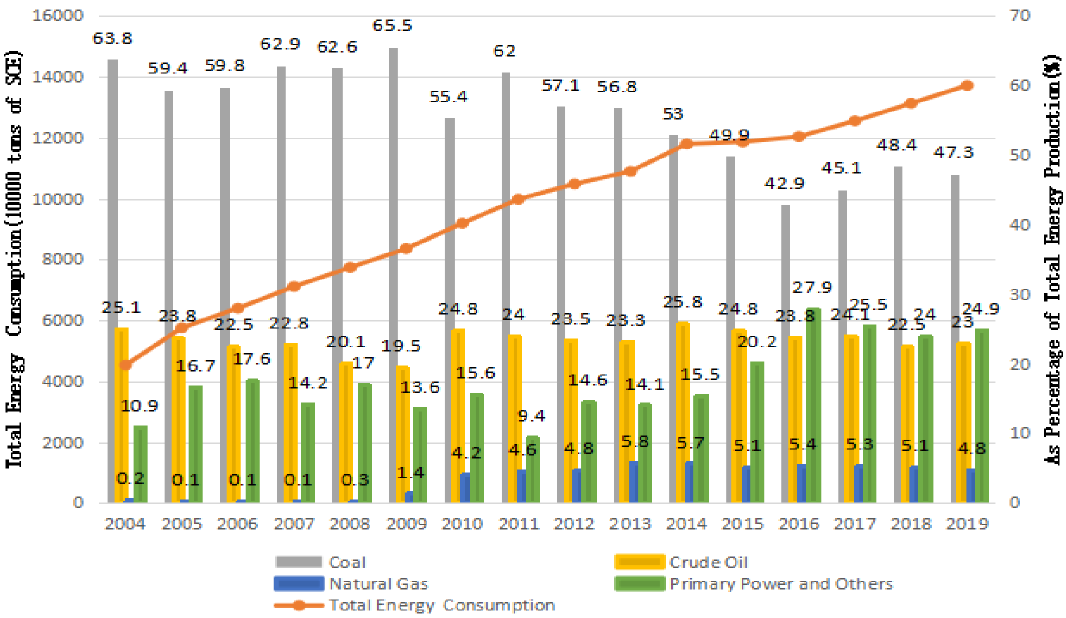

Fig.1 Total Consumption of Energy and Its Composition in 2019

3. Methodology

The GM (1, 1) is an important part of grey system theory, and it is widely used as a forecasting tool for dealing with the systems with uncertain and imperfect information [2]. Now, this method has been applied in many fields. For instance, Wang et al. illustrated the application of new optimized method through a numerical example and compared with prediction values between the original GM (1, 1) model and the modified GM (1, 1) model [3]. Zhao et al.applied the DE-GM (1, 1) to forecast the per capita annual net income of rural households in China [4]. Pao et al.used an improved grey model to predict the carbon emissions, energy consumption and economic growth in China [5]. Zhou et al. proposed a Generalized GM (1, 1) model based on GM (1, 1) and DGM (1, 1) models to forecast the fuel production in China during the period of 2003-2010, and so forth. Furthermore, the grey forecasting model GM (1, 1) can even be established with small amounts of data [6]. Given the non-negative aboriginal sequence as

$X^{(0)} = (x^{(0)}(1), x^{(0)}(2), ..., x^{(0)}(k), ..., x^{(0)}(n))(k = 1, 2..., n)$,

where $x^{(0)}(i)$ is the system output at time i. Then the procedures of GM (1, 1) can be expressed as follows:

Step 1: Construct $X^{(1)}$

$X^{(1)}$ is the first-order accumulated generating operation (1-AGO) of $X^{(0)}$, which can be expressed as

$$X^{(1)} = (x^{(1)}(1), x^{(1)}(2), ..., x^{(1)}(k), ..., x^{(1)}(n))(k = 1, 2..., n) \quad (1)$$

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

Step 2: Define the background value $z^{(1)}(k)$

$$z^{(1)}(k) = 0.5x^{(1)}(k) + 0.5x^{(1)}(k-1)(k = 1, 2, ..., n) \quad (2)$$

Then, the grey differential equation of GM (1, 1) is given by Eq. (3)

$$x^{(0)}(k) + az^{(1)}(k) = b \quad (3)$$

Where, the parameter a is the developing coefficient and b is the grey input.

Step 3: Estimate the values of a and b.

The values of a and b can be estimated by applying the least-square method with the aid of

$\hat{a}=[a,b]^T$. If $\hat{a}=[a,b]^T$ is the parameter row in model GM (1, 1), $Z^{(1)}=(z^{(1)}(1),z^{(1)}(2),\ldots,z^{(1)}(k),\ldots,z^{(1)}(n))$, and

$$B=\begin{bmatrix}-z^{(1)}(2) & 1\\ -z^{(1)}(3) & 1\\ \vdots & \vdots\\ -z^{(1)}(n) & 1\end{bmatrix},\quad Y=\begin{bmatrix}x^{(0)}(2)\\ x^{(0)}(3)\\ \vdots\\ x^{(0)}(n)\end{bmatrix}$$

Then, the least-square state estimation of parameter in model GM (1, 1) is

$$\hat{a}=[a,b]^T=(B^TB)^{-1}B^TY \quad (4)$$

Step 4: Determine the whitenization differential equation and time response equation

The determination of whitenization differential equation of model GM (1,1) is

$$\frac{dx^{(1)}}{dt}+ax^{(1)}=b \quad (5)$$

And the time response function of grey differential equation is

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

Step 5: Calculate the reductive value $\hat{X}^{(0)}$

$$\hat{X}^{(0)}=(\hat{x}^{(0)}(1),\hat{x}^{(0)}(2),\ldots,\hat{x}^{(0)}(k),\ldots,\hat{x}^{(0)}(n)) \quad (7)$$

Where, $\hat{x}^{(0)}(k)=a^{(1)}\hat{x}^{(1)}(k)=\hat{x}^{(1)}(k)-\hat{x}^{(1)}(k-1)$

Step 6: error test

This paper uses the relative percentage error (RPE) analysis to exam the precision of the proposed forecasting model. The RPE is defined as

$$RPE=\left|\frac{x^{(0)}(k)-\hat{x}^{(0)}(k)}{x^{(0)}(k)}\right|\times 100\%(k=2,3,\ldots,n) \quad (8)$$

Then, the total model precision can be defined by average relative percentage error (ARPE) as follows [7]

$$ARPE=\frac{1}{n}\sum_{k=2}^{n}\left|\frac{x^{(0)}(k)-\hat{x}^{(0)}(k)}{x^{(0)}(k)}\right|\times 100\%(k=2,3,\ldots,n) \quad (9)$$

The criterion of ARPE is listed in Table 1 [8], which is used for judging whether the proposed forecasting model is suitable for predicting the energy consumption or not. And when the criterion of ARPE is at acceptable level, the proposed forecasting model is reasonable and the prediction values are accepted.

Table 1 Criterion of Arpe

ARPE (%)	Forecasting power
>50	inaccurate
20-50	Reasonable
10-20	Good
<10	excellent

4. Data Source

Data of energy consumption from 2009 to 2019 used in this paper is given by Statistical Yearbook of Fujian Province in Fujian Province from 2010-2020, as shown in Table 2. Then, the application of grey forecasting model GM (1, 1) for estimating Fujian Province's energy consumption in 2025 will be constructed based on the data shown in Table 2.

Table 2 Data of Energy Consumption from 2009 to 2019

Year	Energy consumption (Total Energy Consumption(10000 tons of SCE))
2009	8353.67
2010	9189.42
2011	9980.23
2012	10479.44
2013	10898.51
2014	11794.37
2015	11862.79
2016	12035.99
2017	12554.74
2018	13131.01
2019	13718.31

5. Results and Discussions

Based on the data shown in Table 2, the data from 2009-2016 is used as the training data for model fitting, while the data from 2017-2019 is used as validation data for further proving the applicability of the proposed model. According to the grey forecasting model GM (1, 1) introduced in section 2, the procedures of estimating Fujian Province's energy consumption in 2025 are described as follows:

The non-negative aboriginal sequence $X^{(0)}$ can be attained directly,

$$X^{(0)} = (8353.670,9189.420,9980.230,10479.440,10898.510,11794.370,11862.790,12035.99) \quad (1)$$

According to the Eq. (1), the 1-AGO sequence $X^{(1)}$ can be expressed as,

$$X^{(1)} = (8353.670,17543.090,27523.320,38002.760,48901.270,60695.640,72558.430,84594.420)$$

(2) The results of background value $z^{(1)}(k)$ as follows:

$$Z^{(1)} = (z^{(1)}(2), z^{(1)}(3), z^{(1)}(4), z^{(1)}(5), z^{(1)}(6), z^{(1)}(7), z^{(1)}(8))$$

$$= (12948.380,22533.205,32763.040,43452.015,54789.455,66627.035,78576.425)$$

(3)The B and Y can be calculated on the basis of Step 3,

$$B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ -z^{(1)}(4) & 1 \\ -z^{(1)}(5) & 1 \\ -z^{(1)}(6) & 1 \\ -z^{(1)}(7) & 1 \\ -z^{(1)}(8) & 1 \end{bmatrix} = \begin{bmatrix} -12948.380 & 1 \\ -22533.205 & 1 \\ -32763.040 & 1 \\ -43452.015 & 1 \\ -54798.455 & 1 \\ -66627.035 & 1 \\ -78576.425 & 1 \end{bmatrix}, \quad Y = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ x^{(0)}(4) \\ x^{(0)}(5) \\ x^{(0)}(6) \\ x^{(0)}(7) \\ x^{(0)}(8) \end{bmatrix} = \begin{bmatrix} 9189.420 \\ 9980.230 \\ 10479.440 \\ 10898.510 \\ 11794.370 \\ 11862.790 \\ 12035.990 \end{bmatrix}$$

Then, the least square method is used to estimate the values of a and b, the values are

$$\hat{a} = \begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} -0.04397 \\ 8933.67810 \end{bmatrix}$$

(4) So, the whitenization differential equation of model GM (1, 1) is

$$\frac{dx^{(1)}}{dt} - 0.04397x^{(1)} = 8933.67810$$

And the time response function of grey differential equation is

$$\hat{x}^{(1)}(k) = (x^{(0)}(1) - \frac{b}{a})e^{-a(k-1)} + \frac{b}{a} = 211536.00415e^{0.04397(k-1)} - 203182.33414 \quad (10)$$

(5) According to the Eqs: (7) and (10), the reductive value $\hat{X}^{(0)}$ is

$\hat{X}^{(0)}$ =（8353.67001,9508.75617,9936.18432,10382.82580,10849.54427,11337.24219, 11846.86264,12379.39103）

Then, the relative percentage error (RPE) and average relative percentage error (ARPE) from 2009-2016 are obtained by Eqs. (8) and (9), as shown in Table 3. In order to further examine whether the grey forecasting model GM (1, 1) is suitable for estimating the energy consumption in this study, the forecasted energy consumption during the period of 2017 to 2019 will be constructed. The final results of energy consumption and ARPE are shown in Table 3.

Table 3 Error Inspection Table

Year	Actual value $x^{(0)}(k)$	Forecasted value $\hat{x}^{(0)}(k)$	RPE(%)
2009	8353.67		
2010	9189.42	9508.75617	3.475
2011	9980.23	9936.18432	0.441
2012	10479.44	10382.82580	0.922
2013	10898.51	10849.54427	0.449
2014	11794.37	11337.24219	3.876
2015	11862.79	11846.86264	0.134
2016	12035.99	12379.39103	2.853
ARPE(%)(2001-2007)		1.736	
2017	12554.74	12935.85711	3.036
2018	13131.01	13517.33690	2.942
2019	13718.31	14124.95479	2.964
ARPE(%)(2008-2010)		2.981	
2020		14759.88571	
2021		15423.35742	
2022		16116.65285	
2023		16841.11261	
2024		17598.13756	
2025		18389.19155	

As illustrated in Table 3, the ARPEs of GM (1, 1) for 2009-2016 and 2017-2019 are 1.736% and 2.981%, respectively. According to the criterion of ARPE (see Table 1), the grey forecasting model GM (1, 1) is excellent for forecasting energy consumption in Fujian Province. Hence, given $k = 17$ and the energy consumption in 2025 can be obtained in the light of Eq. (10). The prediction value of Fujian Province's energy consumption in 2025 is 18389.191 $\times 10^4$ tons of SCE.

6. Conclusions

In this paper, the grey forecasting model GM (1, 1) is employed to predict the Fujian Province's energy consumption in 2015 based on the data from 2000-2010. The results show that the ARPEs of GM (1, 1) for 2009-2016 and 2017-2019 are 1.736% and 2.981%, respectively. It indicates that the proposed model has high reliability and validity for predicting the energy consumption.

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