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Prediction of Rural Energy Consumption Based on the Gray Theory in Hebei Province

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Abstract

Rural energy is the cornerstone of the development of economy, as a major agricultural province, the scientific prediction on rural energy consumption is particularly important in Hebei Province. In this paper, the GM (1,1) model of the grey theory was used to predict the rural energy consumption as well as the proportion of total energy consumption ratio of Hebei Province, in 2015 the rural energy consumption would reach 833.18 million tons of standard coal, the total energy consumption ratio would reach 28.39%, and the relative error and posterior test are all qualified. Finally, It can provide a scientific basis for the development of energy strategy planning of Hebei Province, and put forward policy recommendations.

Keywords: *grey theory, energy consumption, GM (1,1) model, prediction*

1. Introduction

In Hebei Province, it has the vast rural area and a wide range of energy. It is the basic decision-making of rural energy construction in Hebei Province by developing and producing energy as an energy supplement. With the increase income of farmers in Hebei Province, farmers living energy quantity is gradually increased. This coal-dominated energy consumption structure, however, is the consumption structure of high pollution, high emissions and high consumption. It is not only inefficient, but also can cause serious consequences of environmental pollution therefore, how to accurately predict the energy consumption and its trends in rural areas of Hebei Province, is the most important issue to address rural energy strategy, but also is the basis for the sustainable development of economy of Hebei Province.

Currently, many scholars and experts at home and abroad have made a lot of research on rural energy consumption. Wang changbo (2010) [1] accounted the carbon emissions of China's rural energy consumption, and showed that the emissions of the rural energy consumption in China accounted for 40% to 60% share of the country's total emissions. Wang Xiaohua (2001) [2] carried retrospect and prospect of Chinese rural household energy consumption, and divided the rural energy consumption for the serious shortage of able stage, basically meet the stage and the commercialization stage. It provided a basis for understanding the law of rural household energy consumption development. Cheng Sheng (2009) [3] forecast the rural energy consumption based on chaos-neural network time series prediction of energy consumption in rural areas. Shi Huading (2010) [4] estimated China's rural energy consumption and major pollutant emissions with emission factor in the period 1980 to 2004, and analyzed the rural energy consumption patterns and environmental effects. Chen Xiaofu (2010) [5] did statistical analysis based on the progress made by China's rural energy industry in the new situation, pointed out the problems and obstacles and put forward suggestions and countermeasures for the sustainable development of the industry. These studies play a positive role in the promotion of rural energy problems, but the direction of their research is mainly focused on rural energy consumption structure, policies, and the impact on the rural environment, it has less scientific prediction on rural energy consumption.

This paper selects 2005-2010 rural energy consumption as well as the proportion of total energy consumption ratio for the original sequence of observations of Hebei Province, constructs gray GM (1,1) model and its long-term prediction. Then, it discovers the general law

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of energy consumption in rural areas of Hebei Province, and provides reference and scientific basis for the formulation of energy development strategy and energy planning.

2. GM (1,1) Model Prediction Principle and Modeling Steps
2.1. The Introduction of GM (1,1) Model

Gray system theory is the study of gray system analysis, modeling, forecasting, decision-making and control theory, and it was put forward by Professor Deng Julong in 1982. It used “small sample” and “poor information” of “section known, some unknown”, which was uncertainty system, as the research object. Through the generation and development of “section known” information, it made extraction of valuable information and did exact description of real events [6]. GM (1,1) prediction model conducts a cumulative generation process with the original data sequence, and generates the new data sequence of strong regularity. And then establishing the corresponding first-order single-variable differential equation model, looking for the regularity of generated data sequence, and being fitted with the solution of differential equations with the law of generated sequence. Then the final arithmetic result to restore a method, which is based on the generation of data [7]. And energy consumption in rural areas is a complex, uncertain gray system, it is influenced by the natural conditions and national macroeconomic policy, its consumption factors showed significant gray. Therefore, energy consumption in rural areas can be treated as a study of gray system to conduct, and we can make introduction of GM (1,1) model to predict.

2.2. Modeling Steps

The modeling and solving steps of gray prediction GM (1,1) model are as follows:

Firstly, the set of original data sequence is:

$$x^{(0)} = \left\{x^{(0)}(1), x^{(0)}(2), x^{(0)}(3), \cdots, x^{(0)}(n)\right\}$$

Making use of 1-AGO (Accumulated Generating Operation) to generate a first-order accumulated generating sequence:

$$x^{(1)} = \left\{x^{(1)}(1), x^{(1)}(2), x^{(1)}(3), \cdots, x^{(1)}(n)\right\}$$

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

Secondly, constructing accumulate matrix B and the data vector Y_n:

$$B = \begin{bmatrix} -\frac{1}{2}\left[x^{(1)}(1) + x^{(1)}(2)\right] & -\frac{1}{2}\left[x^{(1)}(2) + x^{(1)}(3)\right] & \cdots & -\frac{1}{2}\left[x^{(1)}(n-1) + x^{(1)}(n)\right] \\ 1 & 1 & \cdots & 1 \end{bmatrix}^T$$

$$Y_n = [\, x^{(0)}(2)\, , x^{(0)}(3)\, ,\ldots, x^{(0)}(n)\,]^T$$

Finally, we establish gray prediction model. Using the least squares method to obtain the least squares approximate solution, it is the development of gray number α and endogenous control of gray number μ:

$$A = \begin{pmatrix} \alpha \\ \mu \end{pmatrix} = \left(B^T B\right)^{-1} B^T Y$$

GM (1,1) prediction model meets the first-order linear differential equations:

$$\frac{dx^{(1)}}{dt} + \alpha x^{(1)} = \mu$$

Solution was:

$$x^{(1)}(t)=\left[x^{(1)}(1)-\frac{\mu}{\alpha}\right]e^{-\alpha t}+\frac{\mu}{\alpha}$$

Written in discrete form ($x^{(1)}(1)=x^{(0)}(1)$), we will get the predictive value of discrete forms:

$$\hat{x}^{(1)}(k+1)=\left[x^{(0)}(1)-\frac{\mu}{\alpha}\right]e^{-\partial k}+\frac{\mu}{\alpha} \quad (k=1,2,\cdots,n)$$

Doing tired less restore, we will get original series of gray prediction model:

$$\begin{aligned}\hat{x}^{(0)}(k+1) &= \hat{x}^{(1)}(k+1)-\hat{x}^{(1)}(k)\\ &= (1-e^{\alpha})(x^{(0)}(1)-\frac{\mu}{\alpha})e^{-\alpha k} \quad (k=1,2,\cdots,n)\end{aligned}$$

3. Prediction Results and Test

3.1. Prediction Results

The basic data used in this study is mainly from China rural Energy Statistical Yearbook [8]. We can obtain the annual total energy consumption in rural areas as well as the proportion of total energy consumption from 2005 to 2010 in Hebei Province, as shown in Table 1:

Table 1. The Rural Energy Consumption as Well as the Proportion of Total Energy Consumption from 2005 to 2010 in Hebei Province

Year	2005	2006	2007	2008	2009	2010
Consumption of rural energy/ million tons of standard coal	625.14	581.38	580.88	625.68	610.27	696.64
Consumption of total energy/ million tons of standard coal	1665.96	1491.69	1523.53	1767.62	1806.33	2173.31
Proportion /%	37.52	38.97	38.13	35.40	33.79	32.05

By using matlab 7.0 to solve the prediction results, as shown in Table 2:

Table 2. Consumption of Rural Energy and Its Prediction

Year	Consumption of rural energy/ million tons of standard coal	Prediction account/ million tons of standard coal	Relative error/%	the proportion of total energy consumption /%	Prediction proportion/%	Relative error/%
2005	625.14	625.14	0	37.52	37.52	0
2006	581.38	567.07	2.46	38.97	39.04	0.07
2007	580.88	591.85	1.89	38.13	38.75	0.62
2008	625.68	617.69	1.28	35.40	37.64	2.24
2009	610.27	644.67	5.63	33.79	36.23	2.44
2010	696.64	672.83	3.42	32.05	35.01	2.96
2011		702.22			34.34	
2012		732.88			32.35	
2013		764.90			30.28	
2014		798.31			29.74	
2015		833.18			28.39	

3.2. The Posteriori Test of Model Accuracy

Posterior test is based on the statistics between the model prediction value and the actual value of the test method, which is ported from the probabilistic forecasting methods. It is based on residuals (absolute error) ε, according to the size of the absolute value of the residuals in each period and the probability of occurrence of smaller point of the residuals, as well as with the size of the variance of prediction error on the indicators [9]. The concrete steps are as follows:

First of all, noting the difference $\varepsilon(k)$ between the actual value $x^{(0)}(k)$ and the calculated value (predicted value) $\hat{x}^{(0)}(k)$ in the moment of k, and this is called k time residuals:

$$\varepsilon(k) = x^{(0)}(k) - \hat{x}^{(0)}(k)\,(k = 1,2,\cdots,n)$$

Then, noting the average value of actual value $x^{(0)}(k)$ ($k = 1,2,\cdots,n$) is $\bar{x}$:

$$\bar{x} = \frac{1}{n}\sum_{k=1}^{n} x^{(0)}(k)$$

And noting the average value of residuals $\varepsilon(k)$ ($k = 1,2,\cdots,n$) is $\bar{\varepsilon}$:

$$\bar{\varepsilon} = \frac{1}{m}\sum_{k=1}^{m} \varepsilon(k)$$

Among it, m is the number of prediction residuals data, generally $m \le n$.

Finally, let's note historical data (actual value) variance as S_1^2, that is:

$$S_1^2 = \frac{1}{n}\sum_{k=1}^{n}\left(x^{(0)}(k) - \bar{x}\right)^2$$

And noting residuals variance as S_2^2:

$$S_2^2 = \frac{1}{m}\sum_{k=1}^{m}\left(\varepsilon(k) - \bar{\varepsilon}\right)^2$$

Then we can get two important data of the posterior testing, that is the posteriori differential ratio C and small error probability P.

$$C = \frac{S_2}{S_1}$$
$$P = P\left\{\left|\varepsilon(k) - \bar{\varepsilon}\right| < 0.6745\, S_1\right\}$$

The smaller indicators C is, the better it is. The smaller C is, the greater S_1 expressed, while the smaller S_2 is. S_1 is big, indicating that the variance of the historical data and discrete degree of historical data are large. S_2 is small, indicating that the residuals variance and residuals degree of dispersion are small. C is small, indicating that the historical data is discrete, but the the difference between predictive value of the model and the actual value are not very discrete [10]. However, the bigger indicators P is, the better it is. The bigger P is, indicating that more points less than the given value $0.6745S_1$ of the difference between the mean value of residuals and residuals.

With two indicators C and P, we can make comprehensive assessment of the accuracy of prediction model, as shown in Table 3:

Table 3. The Small Error Probability (P) and Posterior Margin Ratio (C) of Comprehensive Assessment of the Predictive Model

prediction accuracy class	P	C	prediction accuracy class	P	C
Good (A)	>0.95	<0.35	Reluctantly (C)	>0.7	<0.45
Qualified (B)	>0.8	<0.5	Unqualified (D)	≤ 0.7	≥ 0.65

Calculating the prediction for rural energy consumption: $S_1^2 = 1508.15$, $S_2^2 = 356.52$, then $C_1 = 0.48$, $P_1 = 0.84$; According to the prediction of proportion of the total energy consumption: $S_1'^2 = 6.09$, $S_2'^2 = 1.43$, then $C_2 = 0.48$, $P_1 = 0.83$. The results show that the prediction model has better prediction accuracy, and can be used for the prediction of rural energy consumption and the proportion of its total energy consumption in Hebei Province.

The table of contents is organized into chart form, as follows:

The results of this prediction show that rural energy consumption in Hebei Province is a clear upward trend, and rural energy consumption will reach 833.18 million tons of standard coal in 2015; But rural energy accounted for the proportion of total energy consumption in Hebei Province is a downward trend, the proportion will reach 28.39% in 2015. The situation of rural energy demand continues to expand, while the supply of commercial energy has been declining in today's international and domestic energy shortages, the construction of new rural energy issues facing increasingly prominent which will lead to rural energy demand continuing to expand. It will lead to enormous challenges to the rural economy and improving of farmers' living standards that hinder the development of rural economy.

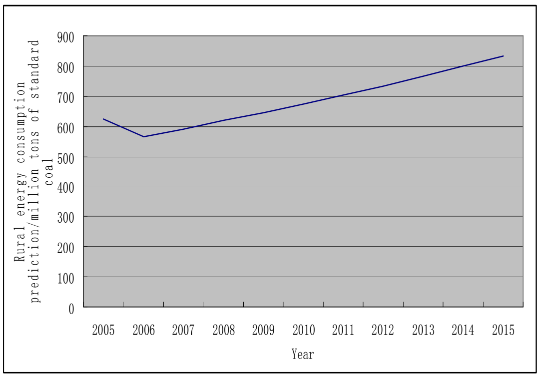

Figure 1. Rural Energy Consumption Prediction from 2005 to 2015

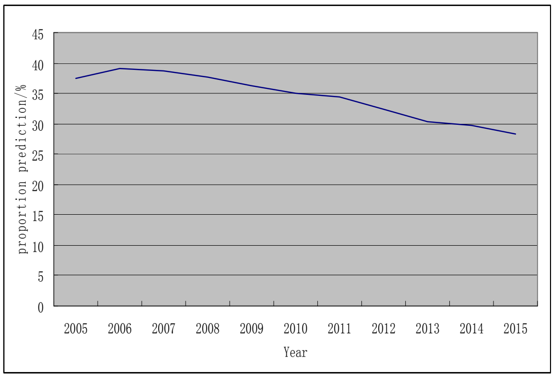

Figure 2. The Proportion of Total Energy Consumption Prediction from 2005 to 2015

4. Conclusion and Policy Recommendation

In this paper, we take the related data of rural energy consumption as well as the proportion of total energy consumption from 2005 to 2010 in Hebei Province and choose the prediction model of GM (1,1). Through this, we predict rural energy consumption in the next five years, as well as the proportion trend of total energy consumption. Thus, the conclusions as follows:

(a) Through the application of GM (1,1) model of rural energy consumption as well as the proportion of the total energy consumption prediction in Hebei Province, the accuracy of both prediction model are qualified and the fitting degree of the predicted results and the actual value is higher. It indicates that applied to the prediction of rural energy consumption as well as the proportion of total energy consumption is feasible and effective, and it can provide a scientific basis for the development of rational rural energy planning strategy for Hebei Province in the future.

(b) Gray GM (1,1) prediction model has the required data, simple arithmetic, and high prediction accuracy, but it is only based on past data to predict future and it does not take the factors of socio-economic changes and changes in government policies into consideration. so the GM (1,1) model is not suitable for long-term forecast, only applied to short-term and medium-term prediction.

(c) The conclusion of prediction indicates that the rural energy problem is still grim in the next five years in Hebei Province. By this, its efforts to the construction of new countryside should be intensified and go for the path of economic development in rural areas.

In view of the main problems of the above conclusions and energy consumption in rural areas of Hebei Province, the paper proposes the following corresponding recommendations:

(a) Rural energy should be included in the energy development system of Hebei Province, which will also help to achieve energy fair. The rural energy is always out of the energy framework that hinders the development of rural economy. This should increase funding and technical input for rural energy and rural energy development needs to have sufficient financial resources and science and technology as a support. Only by following the road of science and innovation, can we solute the problem of energy consumption in rural areas faster and better.

(b) Increasing the development of renewable energy. With the growing amount of energy consumption in rural areas of Hebei Province, and the characteristics of non-renewable and scarce of primary energy that it will eventually face depletion. therefore, we urgently need to speed up the development and utilization of renewable energy and new energy [11]. Renewable energy includes biomass energy, solar, biogas and wind energy, the development and utilization of these energy sources directly to a massive increase in the supply of rural energy, and thus that can solute the energy shortage problems fundamentally in rural areas.

(c) Conserving energy and taking into account the environment. According to the rural energy consumption structure and trends in Hebei Province, it is very difficult to achieve good condition during short period of time. Therefore, it should be based on technological progress and scientific innovation as the guide to improve the efficiency of energy conversion and utilization. This is in line with the economic growth mode from extensive to intensive changing, and also help to reduce the excessive dependence of economic growth on energy. At the same time, you can not only emphasizes energy development, while ignoring the protection of the rural environment. Rural energy development must take into account the environment, only in this way can we ensure the sustainable development of rural energy in Hebei Province.

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References

[1] Wang Changbo, Zhang Lixiao, Li Guangsheng. Carbon Emissions Accounting for Energy Consumption in China's Rural Areas. *Journal of Agricultural Engineering*. 2010; 27(1): 6-11.
[2] Feng Zhenmin, Wang Xiaohua. Phasing Study of Rural Household Energy Consumption in China. *China biogas.* 2001; 19(1): 46-49.
[3] Cheng Sheng. The Rural Energy Consumption Prediction Based on Chaos-neural Network Time Series. *Agrotechnical Economics*. 2009; 3: 67-71.
[4] Shi Huading, Qi Yongqing. Environmental Effects of Energy Consumption in Rural Areas. *Population, Resources and Environment in China*. 2010; 27(1): 6-11.
[5] Chen Xiaofu, Wang Zhengyuan. China Rural Energy Industry Development Status in 2009. *Renewable Energy*. 2010; 28(4): 1-4.
[6] Deng Julong. Control Problems of Grey Systems. *Systems & Control Letters*. 1982; 1(5): 288-294.
[7] Guan Yong, Zhu Cheng. Impact Factor Analysis and Scale Forecast of Tourism Demand in China. *Henan Science*. 2007; 25(3): 513-516.
[8] National Bureau of Statistics. The Rural China Energy Statistical Yearbook. Beijing: China Statistics Press. 2005-2010.
[9] Xiao Guoquan. Power Load Forecasting. Beijing: China Electric Power Press. 2001.
[10] Guo Ping, Lai kunpeng. The Research on Our Regional Farmers Living Energy. *Journal of Anhui Agricultural Sciences*. 2009; 37(23): 11236-11237.
[11] Li Xiangyi, Li Xiuhong. Energy Consumption and Energy Consumption Structure Prediction Which is Based on Gray GM (1,1) Model in Shandong Province. *Environment and Sustainable Development*. 2012; (5): 67-72.