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Research on Electrical Energy Consumption Efficiency Based on GM-DEA

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Abstract

In today's environment which emphasis on energy efficiency, predicting the trend of electrical energy consumption efficiency, and researching the efficient operation model of power industry has practical significance. By establishing GM-DEA method system, we use GM model to predict four inputs and output indicators in 2011 and 2012 in Beijing first, and then use DEA to give predicting years a reasonable analysis for the efficiency of energy consumption. The result shows that efficiency of electrical energy consumption in Beijing is gradually increasing, GM-DEA model can analyze the trend of the efficiency effectively in advance, and it provides a scientific basis for the rapid development of power industry.

Keywords: *electrical energy, consumption efficiency, Grey model, data envelopment analysis*

1. Introduction

Electrical energy is an indispensable strategic resource for every country, it is also essential in our daily life. It plays an important role in sustaining socio-economic development and improving the living standard. In recent years, steady and rapid development of China's economy is greatly increased the demand for electrical energy, the trend that economic dependents on electrical energy is also continue to strengthen.

Under the environment of the rapid development of China's power industry, there are still exist phenomenon that energy efficiency wastes seriously and energy consumption is low. As commodities such as electricity is sensitive and has a long construction period, only establish the early prediction and analysis can we truly achieve the requirement of "economic development, power first". Establish the early prediction and analysis can also lay the foundation for planning the electrical energy consumption solutions.

Nowadays, many scholars have analyzed and investigated China's electric energy consumption from different perspectives [1-5] based on different research methods [6-12]. Banker R.D [6] (1986) compared three situations which are the fixed other non-energy inputs, reduce energy factor alone and reduce all input factors one time with the input-oriented DEA model, the result showed that the former can save more energy. Qun-wei Wang [7] (2008) looked the electricity consumption, labor and capital stock as input indicators ,and looked GDP as the output indicator, studied the efficiency of electricity consumption in different part of China, and analyzed the impact factors related to electricity consumption efficiency using of DEA method. Cui he-rui [13] (2014) used GM (1,1) model of the grey theory to predict the rural energy consumption as well as the proportion of total energy consumption ratio of Hebei Province. Yi Zhang [14] (2013) used DEA model to calculate, analysis reasons for poor benefit of decision-making unit, find out improvement direction and quantity for changing.

Most scholars has much deep study in comprising the energy efficiency in different regions ,there are also much study on the issues of factors which influence electrical energy consumption significantly, but there is less scholar to conduct a systematic study on the efficiency of electrical energy consumption in Beijing using GM-DEA model. Therefore, the study of efficiency of power energy consumption in Beijing has an important value for achieving energy saving in the region.

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2. Building Model and Selecting Indicators

Gray model is a model which looks every random variables as the study target, looks a random process as a gray process relate to a certain range variation and time. the gray system is characterized by part of the information system is known, part of the information is unknown, and it has many advantages, such as the sample data is less required, no need to calculate statistical features, etc. In the gray system studies, GM (1, 1) model has been recognized and followed closely by researchers both at home and abroad from operational angle to theoretical angle. Modeling steps of GM (1, 1) are as follows:

Calculate the accumulated generating sequence of original sequence. Accumulate the original sequence $x^{(0)} = (x^{(0)}(1), x^{(0)}(2)...x^{(0)}(n))$ once and generate the sequence, that is $x^{(1)} = (x^{(1)}(1), x^{(1)}(2)\ldots x^{(1)}(n))$.

Parameter Estimation. In accordance with the law of exponential growth, we can see the following first-order linear differential equations:

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = u \qquad (1)$$

($x^{(1)}$ is the function of time t, it is the gray equation, part of the data is unknown) Kee $A = \begin{pmatrix} a \\ u \end{pmatrix}$ is pending. After the discretization we get $Y_n = BA$. Using the MATLAB software, we can obtain the approximate solution:

$$A = (B^T B)^{-1} B^T Yn = \begin{pmatrix} \hat{a} \\ \hat{u} \end{pmatrix}, \qquad (2)$$

Among the formula $B = \begin{bmatrix} -\frac{1}{2}[x^{(1)}(1) + x^{(1)}(2)] & 1 \\ -\frac{1}{2}[x^{(1)}(2) + x^{(1)}(3)] & 1 \\ \cdots & \\ -\frac{1}{2}[x^{(1)}(n-1) + x^{(1)}(n)] & 1 \end{bmatrix}$, $Y_n = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \cdots \\ x^{(0)}(n) \end{bmatrix}$

Take the approximation $\hat{a}$, $\hat{u}$ into the original differential equation:

$$\frac{dx^{(1)}}{dt} + \hat{a}x^{(1)} = \hat{u} \qquad (3)$$

Get the predicted value of $x^{(1)}$. Approximate solution of the original differential equation is:

$$x^{(1)}(t) = [x^{(1)}(1) - \frac{\hat{u}}{\hat{a}}]e^{-\hat{a}t} + \frac{\hat{u}}{\hat{a}}, \text{ t=1, 2, …, n} \qquad (4)$$

Written the approximate solution of differential equations in the original discrete form, we can get the predicted values that is:

$$\hat{x}^{(1)}(k+1) = [x^{(0)}(1) - \frac{\hat{u}}{\hat{a}}]e^{-\hat{a}(k+1)} + \frac{\hat{u}}{\hat{a}}, \text{ k=0, 2, …, n;} \qquad (5)$$

Get the predicted value of $x^{(0)}$.

$$\hat{x}^{(0)}(k+1)=[x^{(0)}(1)-\frac{\hat{u}}{\hat{a}}]e^{-\hat{a}(k)}(e^{-a}-1)\quad k=0,\ 2,\ \ldots,\ n \tag{6}$$

Model checking. Posteriori error test and small error probability test. The historical data variance is $S_1^2=\frac{1}{n}\sum_{i=1}^{n}(x^{(0)}(k)-\overline{x}^{(0)})^2$. The historical average is $\overline{x}^{(0)}=\frac{1}{n}\sum_{k=1}^{n}x^{(0)}(k)$. The residual variance is $S_2^2=\frac{1}{n}\sum_{i=1}^{n}(\varepsilon(k)-\overline{\varepsilon})^2$. The mean residual is $\overline{\varepsilon}=\frac{1}{n}\sum_{k=1}^{n}\varepsilon(k)$.

Evaluate the Efficiency of Electric Energy Consumption Using DEA Model. DEA's basic idea is to make the appropriate evaluation for each decision-making unit through establish a mathematical programming model. For the evaluation system has n DMU, suppose there are x_0 kinds of input, y_0 kinds of output, σ is the efficiency values of DMUj0, x_j is a collection of input element, y_j is a collection of output element, λ_j is a ratio, s^- and s^+ are the slack variables, they form the BCC-DEA model under VRS together.

The BCC-DEA model is as follows: min σ

$$St.\begin{cases}\sum_{i=1}^{n}\lambda_j x_j+s^-=\sigma x_0\\ \sum_{j=1}^{n}\lambda_j x_j-s^+=y_0\\ \sum_{j=1}^{n}\lambda_j=1\\ \lambda_j,s^-,s^+\geq 0,\ j=1,2,\ldots\ldots,n\end{cases} \tag{7}$$

The optimal solution in Equation (7), if $\sigma=1$, the decision-making unit is efficiency, if $\sigma<1$, the decision-making unit is non-DEA efficiency.

Indicator Selecting. Assume that Beijing's economic activity requires inputs of capital stock, labor, energy consumption and output of GDP. Selecting the data of 2005-2010, and using of GM (1, 1) model and DEA model to evaluate the efficiency of electrical energy consumption. Data of labor, energy consumption and the GDP are all from the "Beijing Statistical Yearbook 2011." The calculate method of the capital stock draws Zhang Jun [4] and others research results directly, and extends the calculation to 2012.

3. Empirical Analysis

Calculate the predicted value of the input-output index; test the Relative error and posterior error with GM (1, 1) model. The results are shown in Table 1 to Table 3.

Table 1. The Original Data of Input and Output Indicators

year	**capital stock** (hundred million)	**Labor** (ten thousand)	**Power energy consumption** (hundred million)	**GDP** (hundred million)
2005	6802.6	878	570.54	7387.8
2006	7316.2	919.7	611.57	8404.4
2007	7829.8	942.7	667.01	9557.8
2008	8343.6	980.9	689.72	10872.2
2009	8857.2	998.3	739.15	12365.6
2010	9380.4	1031.6	809.9	14064.5

Table 2. The Gray Forecast Results of Input and Output Indicators

year	**capital stock** (hundred million)		**Labor** (Ten thousand)		**Power energy consumption** (hundred million)		**GDP** (hundred million)	
	Actual value	Predictive value	Actual value	Predictive value	Actual value	Predictive value	Actual value	Predictive value
2005	6802.6	6906.4	878	893.5	570.54	572.3	7387.8	7387.8
2006	7316.2	7346.1	919.7	919.5	611.57	612.1	8404.4	8404.4
2007	7829.8	7813.2	942.7	946.3	667.01	654.5	9557.8	9557.8
2008	8343.6	8311.1	980.9	973.8	689.72	700	10872.2	10872.2
2009	8857.2	8839.7	998.3	1002.1	739.15	748.5	12365.6	12365.6
2010	9380.4	9402.5	1031.6	1031.2	809.9	800.5	14064.5	14064.5
2011		10001.3		1061.2		856		15997.8
2012		10637.9		1092		915.4		18196.7

Table 3. The Accuracy of the Input and Output Indicators

year	**capital stock** (hundred million)				**Labor** (Ten thousand)				**Power energy consumption** (hundred million)				**GDP** (hundred million)			
	Actual value	Predictive value	Residuals	Relative error %	Actual value	Predictive value	Residuals	Relative error %	Actual value	Predictive value	Residuals	Relative error %	Actual value	Predictive value	Residuals	Relative error %
2005	6802.6	6906.4	103.8	1.5	878.0	893.5	15.5	1.8	570.5	572.3	1.8	0.3	6969.5	7387.8	418.3	6.0
2006	7316.2	7346.1	29.9	0.4	919.7	919.5	-0.2	0.0	611.6	612.1	0.5	0.1	8117.8	8404.4	286.6	3.5
2007	7829.8	7813.2	-16.6	0.2	942.7	946.3	3.6	0.4	667.0	654.5	-12.5	-1.9	9846.8	9557.8	-289.0	-2.9
2008	8343.6	8311.1	-32.5	0.4	980.9	973.8	-7.1	-0.7	689.7	700	10.3	1.5	11115	10872.2	-242.8	-2.2
2009	8857.2	8839.7	-17.5	0.0	998.3	1002.1	3.8	0.4	739.2	748.5	9.4	1.3	12153	12365.6	212.6	1.7
2010	9380.4	9402.5	22.1	0.0	1031.6	1031.2	-0.4	0.0	809.9	800.5	-9.4	-1.2	14113.6	14064.5	-49.1	-0.3
2011		10001				1061.2				856				15997.8		
2012		10638				1092				915.4				18196.7		
The average accuracy %			99.6		The average accuracy %		99.7		The average accuracy %		99		The average accuracy %		97.2	
Posterior error %			0.04		Posterior error %		0.13		Posterior error %		0.11		Posterior error %		0.28	

Test results of Gray prediction are above the table, relative error of each index average is less than 10%, and accuracy is more than 90%. Posterior error ratio is less than 0.35; value of small probability error is 1. Residual test and Posterior error test show that the model can get a very good prediction result; it can be used for follow-up study.

DEA Evaluation of Efficiency of Electrical Energy Consumption Based on the historical data of the input and output elements and gray predictive value of each element in 2011 and 2012, using DEAP (Version 2.1), we calculate the overall efficiency, technical efficiency, scale efficiency and slack variable distribution of Beijing electric energy consumption in 2005-2012, results are shown in Table 4 and Table 5.

Table 4. DEA Evaluation of Electrical Energy Consumption in Beijing

year	crste	vrste	scale	scale efficiency
2005	0.651	1	0.651	Increase
2006	0.691	0.986	0.701	Increase
2007	0.721	0.977	0.738	Increase
2008	0.790	0.988	0.802	Increase
2009	0.842	0.987	0.853	Increase
2010	0.877	0.979	0.895	Increase
2011	0.940	0.988	0.952	Increase
2012	1.000	1.000	1	constant

Table 5. Distribution of Electrical Energy Consumption Slack Variable (s^-)

year	2005	2006	2007	2008	2009	2010	2011	2012
s^-	0	-50.058	-76.68	-207.745	-170.996	-14.025	-23.611	0

From Table 4 we know that the comprehensive efficiency in 2011 is less than 1 but very close to 1, it is non-DEA efficient. All the electrical energy efficiency values in 2012 are 1, it reaches the optimal state, it indicates that the input and output in 2012 is more reasonable. Combined with the results of previous year's data we can see that Beijing's overall efficiency of electrical energy consumption is increasing, it indicates that electrical consumption efficiency of Beijing is gradually increasing. The table also shows that electrical energy consumption in 2011 is increasing; this means that the demand for electrical energy in 2011 is urgent. GDP will increase with electrical energy consumption growth, and GDP growth ratio is greater than the proportion of electrical energy consumption.

Table 5 shows that slack variables in 2011 is not 0, it means Beijing's electric energy consumption is high; this results in a waste of electrical energy. In 2012, the electrical consumption slack variable is 0, energy consumption is reasonable. The slack variables in the year are approaching 0; it indicates that Beijing's efficiency of electrical energy consumption increases year by year.

4. Conclusion

The power industry is the most important basic energy industry in economic development; it operates efficiency or not will directly affect the sustainable development of the national economy and the quality of people's life. In order to ensure electric energy supply adequately and efficiently, electricity investment must be arranged based on social and economic development in advance, we should endeavor to ensure that there is no power shortage, and take efforts to realize the efficiency operation of electric power industry. Therefore, the efficiency of power energy consumption in China should be improved without delay, it has great significance to predict and evaluate electrical energy consumption effectively.

GM-DEA model provides a new idea for the research of power energy consumption, especially in the present, much history data of the input and output indicators are missing, using of gray forecasting to predict future energy inputs can achieve high fitting accuracy. This paper uses efficiency of Beijing's electrical energy consumption as an example, based on gray prediction method and the forecasting data, using DEA technique to evaluate the predicted results, we can managed to get a lot of useful information and advice, GM-DEA provides a theoretical support which makes electrical energy more efficiency. GM-DEA helps to achieve optimal allocation of resources; it also provides a reliable basis for production and distribution of the electric energy.

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