Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 13 (20): 4327-4331, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.4327.4331

Modeling and Simulation of Regional Energy Consumption Prediction of Henan Province Considering Urban Expansion Based on Inverse GM (1, N) in China

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Abstract: In China today regional energy consumption is affected by urban expansion. Urban expansion should consider the bearing capacity of urban and social resources. In this study, energy consumption forecast considering the urban expansion is proposed. Firstly GM(1, N) is proposed and applied to energy consumption forecasts. Then the case of energy consumption forecast is given based on GM(1, N). The results show that compared with urban expansion does not be considered, considering the energy consumption of urban expansion has a huge difference. Considering urban expansion in China's energy consumption has greater objectivity.

Key words: Regional energy consumption, urban expansion, GM (1, N), China

INTRODUCTION

Analysis of energy often is studied for that it is a key factor for countries and regions (Watanabe and Wang, 2007; Hu and Wang, 2006). In different countries, the impact factors of energy consumption may not be the same situation. Now urban expansion greatly is exacerbating energy consumption in China. The city's rapid "grow up", the process of urbanization in China is becoming a prominent feature. The data from satellite images of the entire country pretty amazing city built-up area in the past 20 years for an increase of more than 2 times. Some of the city's expansion of built-up area is more than 20 times. These factors confirm the ongoing human history, Chinese largest and fastest urbanization. From 1990-2000, Chinese urban built-up area increased from 12,200-21,800 km^2, an increase of 78.3%. Until 2010 this data reached 40,500 km^2 and an increase of 85.5% (Wang *et al*., 2012). Data in 2010 was more double than that in 1990.

It can be seen from the productive sector of energy consumption can be relatively easy to draw directly the same conclusion. But without considering the difference between the city and the hinterland it is difficult to explain the city as the main place of energy consumption of the real reason. With urban development energy considering production sector and energy consumption in the city urban development, economic factors, demographic factors and spatial factors impact on energy consumption. In the city's comprehensive development the impact of energy consumption factors becomes increasingly important. Urban energy consumption is not only to consider the city's population size, economic growth and the expansion of space, but also is to combine the various factors into account in order to obtain comprehensive and comparative conclusions (Brownstone and Golob, 2009). In fact the various elements of urban development are always intertwined with the urban development of population expansion, economic growth and spatial expansion. Each of which factors is associated with other factors working together to produce a composite effect. Some mutual offset or some mutually reinforcing is the result of its role in the existence of interactivity. However, these studies have only looked at the impact of energy consumption in the face of part. No considering the sum of the interaction among these factors results in the incomplete analysis of energy consumption.

It is different from previous studies that this study considers the impact of urban expansion. This is suitable for Chinese special situation. China's urban expansion is a serious and worthy of attention. "Erdos ghost appeared" is a famous example to depict the city "Erdos" where is an empty where city nobody lives. Urban expansion has brought a lot of energy consumption. Unplanned expansion of unplanned energy consumption caused a large number of inefficient wastes. Therefore, it is necessary to analyze the urban expansion impact on energy consumption in China. In this study, energy consumption of Henan Province in China is studied.

MODELING METHOD BASED ON INVERSE GM(1, N)

The inverse GM(1, N) model can be referred in the literature which the author of this study has published. The methods and contents are in the following (Wang, 2013):

There are N initial datum sequences in the following equation:

$$X_i^{(1)} = (X_i^{(1)}(1), X_i^{(1)}(2), \cdots, X_i^{(1)}(n)) \quad i = 1, 2, \cdots, N \tag{1}$$

The initial datum sequences are executed the Inverse Accumulated Generating Operation (IAGO) to produce the following sequence $x_i(0)$:

$$x_i^{(0)} = (x_i^{(0)}(1), x_i^{(0)}(2), \ldots, x_i^{(0)}(n)) \tag{2}$$

In above sequence, $x^{(0)}$ is calculated by following equation:

$$x_i^{(0)}(k) = x_i^{(1)}(k+1) - x_i^{(1)}(k) \; (k = 1, 2, \ldots, n) \tag{3}$$

$X_i^{(1)}$ is viewed as constant variable at time t(k = 1, 2,..., n), $X_i^{(1)}$ is viewed as the function of t:

$$X_i^{(1)} = X_i^{(1)}(t) \tag{4}$$

If $X_2^{(1)}$, $X_3^{(1)}$,..., $X_N^{(1)}$ have the affection on variation ratio of $X_1^{(1)}$ then the following differential equation can be created:

$$\frac{dX_1^{(1)}}{dt} + aX_1^{(1)} = b_1 X_2^{(1)} + b_2 X_3^{(1)} + \cdots + b_{N-1} X_N^{(1)} \tag{5}$$

The above differential equation is recorded as GM (1, N) (Deng, 1982).

In the differential equation the parameters are represented as:

$$\alpha = (a, b_1, b_2, \ldots, b_{N-1})^T \tag{6}$$

Ordering:

$$Y_N = (X_1(0)(2), X_1(0)(3), \ldots, X_1(0)(n))^T \tag{7}$$

Difference discrete is executed on this differential equation, the following linear equation groups can be gained:

$$Y_N = B\hat{\alpha} \tag{8}$$

According to least square method the following formula can be induced:

$$\hat{\alpha} = (B^T B)^{-1} B^T Y_N \tag{9}$$

The two-moving-average method is used to gain the following matrix:

$$B = \begin{pmatrix} -\frac{1}{2}(X_1^{(1)}(1) + X_1^{(1)}(2)) & X_2^{(1)}(2) & \cdots & X_N^{(1)}(2) \\ -\frac{1}{2}(X_1^{(1)}(2) + X_1^{(1)}(3)) & X_2^{(1)}(3) & \cdots & X_N^{(1)}(3) \\ \vdots & \vdots & & \vdots \\ -\frac{1}{2}(X_1^{(1)}(n-1) + X_1^{(1)}(n)) & X_2^{(1)}(n) & \cdots & X_N^{(1)}(n) \end{pmatrix} \tag{10}$$

Then $\hat{\alpha}$ can be resolved, the differential equation is also resolved.

If n-1<N then the number of equations in linear equation groups 2 is few than unknown number. Then $B^T B$ is singular matrix, $\hat{\alpha}$ can not be resolved by the Eq. 3. So, M is introduced to execute the weighted minimization of $\alpha^T \alpha$.

Ordering:

$$M = \mathrm{diag}(\alpha_1, \alpha_2, \ldots, \alpha_N) \tag{11}$$

Then $\hat{\alpha}$ can be calculated by the following equation:

$$\hat{\alpha} = M^{-1} B^T (BM^{-1} B^T)^{-1} Y_N \tag{12}$$

The scope and verification are in the following (Deng, 1989a):

- **Scope of inverse GM(1, n):** When $-\hat{\alpha} \leq 0.3$ the inverse GM(1, n) can produce behavior of system for the medium and long period. When $0.3 < -\hat{\alpha} \leq 0.5$, the inverse GM(1, n) can produce behavior of system for the short period. When $0.5 < -\hat{\alpha} \leq 0.8$ it should be cautiously used to analyze behavior of system for the short period. When $0.8 < -\hat{\alpha} \leq 1$, residual correction should be sued. When $-\hat{\alpha} > 1$, inverse GM(1,1) can not be used to create differential equation to analyze the behavior of system
- **Verification of inverse GM(1, 1):** The sequence of residual is in the following:

$$\varepsilon^{(0)} = (\varepsilon^{(1)}, \varepsilon^{(2)}, \ldots, \varepsilon^{(n)}) = (x^{(0)}(1) - \hat{x}^{(0)}(1), \; x^{(0)}(2) - \hat{x}^{(0)}(2) \ldots x^{(0)}(n) - \hat{x}^{(0)}(n)) \tag{13}$$

The even $\bar{\varepsilon}$ and variance S_ε^2 of residual is calculated in the following (Liu and Lin, 2011):

$$\bar{\varepsilon} = \frac{1}{n} \sum_{k=1}^{n} \varepsilon(k) \tag{14}$$

$$S_\varepsilon^2 = \frac{1}{n} \sum_{k=1}^{n} (\varepsilon(k) - \bar{\varepsilon})^2 \tag{15}$$

The even $\bar{x}$ and variance S_x^2 of $X^{(0)}$ is calculated in the following:

Table 1: Reference of levels of table of verification of precision

Index	Levels	C	P
One	Good	0.35	0.95
Two	Qualified	0.50	0.80
Three	Qualified with difficulty	0.65	0.70
Four	Not qualified	0.80	0.60

$$\bar{x} = \frac{1}{n}\sum_{k=1}^{n} x^{(0)}(k) \tag{16}$$

$$S_x^2 = \frac{1}{n}\sum_{k=1}^{n} (x^{(0)}(k) - \bar{x})^2 \tag{17}$$

Posterior ratio C is calculated by the following equation:

$$C = \frac{S_e}{S_x} \tag{18}$$

The probability of Small error p is calculated by the following equation:

$$p = P(|\varepsilon(k)-\bar{\varepsilon}|<0.674\ S_x) \tag{19}$$

In the above equations it is good if the c is smaller and p is bigger. The reference table of levels of verification of precision (Mao and Chirwa, 2006; Deng, 1989b).

CASE OF MODELING AND SIMULATION OF REGIONAL ENERGY CONSUMPTION PREDICTION BASED INVERSE GM(1, N)

Case and modeling: The main impact factors for the consumption of energy of Henan province in China are in the following:

- **Economic growth:** First, as a general increase in living standards, with the increasing of refrigerators, air conditioning, heating, computers, televisions, cars and other household goods a lot of growth is brought in the number of families which resulted in increased energy consumption, number of universality. Secondly with China's rapid economic development China built a number of industrial enterprises which consume a lot of energy every day. GDP is a measure of gross domestic product an important factor in economic development. GDP growth includes about agriculture, industry, construction and other aspects of growth. Among them, industry, construction, transport industry need to consume a lot of energy. The level of science and technology promote increased levels of energy consumption. Energy consumption in the past will not consider the commonplaces in everyday lighting and industrial enterprises. This creates a vicious circle, the more the economy is developed the more energy consumption is produced. The economic development is the most fundamental reason in the total energy consumption.
- **Population growth:** With the Chinese population growth the household consumption, household water consumption and other aspects are increasing. Moreover everyone is a bottomless pit from birth to death. Everyone will consume countless energy. In our daily life of each person clothing, food, housing, transportation, entertainment and other aspects will consume energy. We should not forget that white plastic bags is manufactured using our resources. But resources are non-renewable
- **Rapid development of urbanization:** With the rapid development of urbanization and urban population continues is growing. Human living conditions and living environment present a huge challenge. It brings not only the growth trajectory of a city but also the pace of urban expansion. Like nature, growth is unstoppable. And sustainable urban development is facing a lot of confusion. How to move towards sustainable development? Experts pointed out that in urban planning development projects should mainly focus on the gradual transition to the protection and rational using of resources. From a focus on nature and functions of the city turned to focus on positioning control and reasonable environmental capacity. Using the scientific construction standards to guide the city in moderation development is right. Avoiding some of big cities sprawl phenomenon is necessary. Reducing the total consumption of energy resources and promote compact urban development intensive is reasonable. Resource-saving and environment-friendly city should be built

The datum for energy consumption, the economic growth, population growth and rapid development of urbanization of Henan are listed in the following Table 2-5.

According to above data using the inverse GM(1, N) to create the following model:

$$\frac{dX_1^{(1)}}{dt} + 1.0788X_1^{(1)} = 0.0104X_2^{(1)} + 6.6697X_3^{(1)} + 34.3297X_4^{(1)}$$

According to above data using the inverse GM (1,1) to create the following models:

$$\frac{dX_2^{(1)}}{dt} - 0.1330X_2^{(1)} = 1448838.9852$$

Table 2: Energy consumption for recent 6 years (10,000 tons of standard coal)

Year	2007	2008	2009	2010	2011	2012
Energy consumption	17838	18976	19752	21438	23061	24986

Table 3: Economic for recent 6 years

Year	2007	2008	2009	2010	2011	2012
Economic (GDP, million)	1,501,246	1,801,853	1,948,046	2,309,236	2,693,103	2,981,014

Table 4: Population for recent 6 years

Year	2007	2008	2009	2010	2011	2012
Population (10,000)	9869	9918	9967	10437	10489	10543

Table 5: Development of urbanization for recent 6 years

Year	2007	2008	2009	2010	2011	2012
Development of urbanization (sq. km)	1572	1857	1913	2014	2098	2159

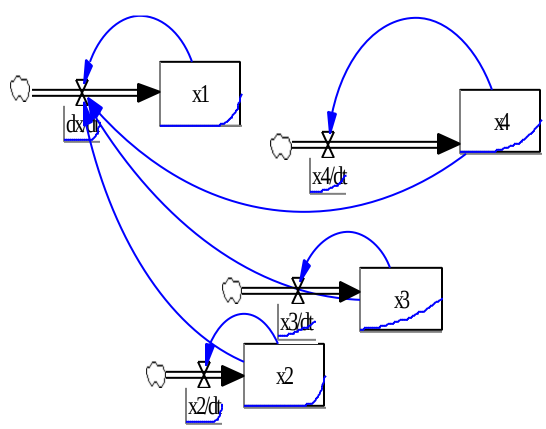

Fig. 1: Impact relation among energy consumption, the economic growth, population growth and rapid development of urbanization

$$\frac{dX_3^{(1)}}{dt} - 0.0171X_3^{(1)} = 966.6134$$

$$\frac{dX_4^{(1)}}{dt} - 0.0392X_4^{(1)} = 175.5626$$

The impact relation among energy consumption, the economic growth, population growth and rapid development of urbanization is shown in Fig. 1.

RESULTS AND ANALYSIS

The above models can be used to gain the following analysis result. In Fig. 2 the future trend for economic from 2013 to 2017 is shown by the above models. The results in Fig. 2 shows that economic will continue to grow from 2013-2017.

The results in Fig. 3 shows that population will continue to grow from 2013-2017.

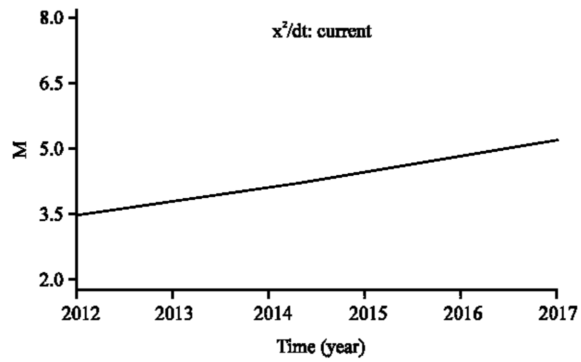

Fig. 2: Future trend for economic from 2013-2017

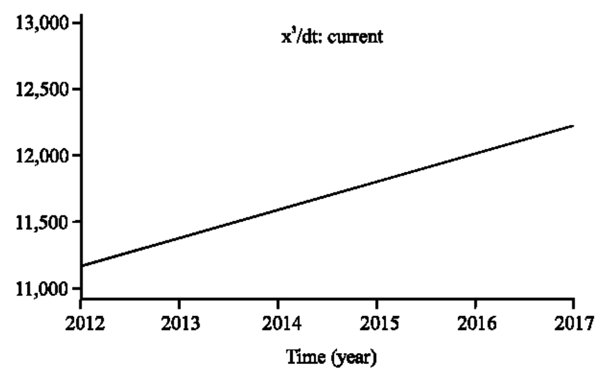

Fig. 3: Future trend for population from 2013-2017

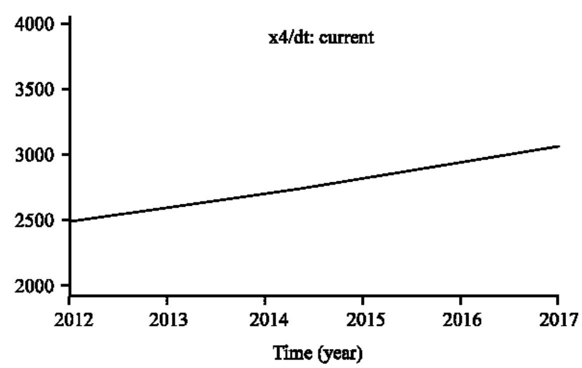

Fig. 4: Future trend for development of urbanization

In Fig. 4 the future trend for development of urbanization from 2013-2017 is shown by the above models. The results in Fig. 4 shows that development of urbanization on will continue to grow from 2013-2017.

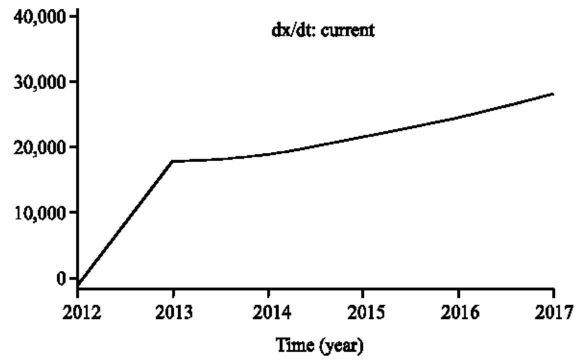

Fig. 5: Future trend for energy consumption from 2013- 2017

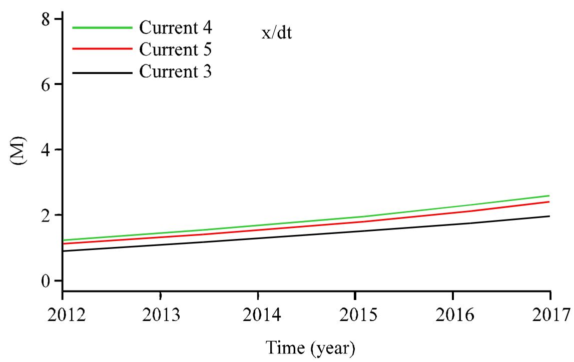

Fig. 6: Future trend for energy consumption from 2013-2017 without considering city expansion

In Fig. 5 the future trend for energy consumption from 2013-2017 is shown by the above models. The results in Fig. 5 show that energy consumption will continue to grow from 2013-2017.

If you do not consider the urban sprawl that energy consumption will be greatly decreased. The situation is shown in Fig. 6. In Fig. 6 shows the three cases, the growth of urban sprawl were given 0, thousandth, five thousandths case energy consumption, respectively represented with the color blue, red and green.

Comparison with the results of Fig. 6, it can be seen in Fig. 5 clearly expressed the urban expansion in China a huge impact on energy consumption. In Fig. 5, energy consumption is relatively fast while the growth rate of urban expansion in between 10 and 30%.

CONCLUSION

This articles starts from the current characteristics of China's urban expansion regional energy consumption. The prediction model considering the urban expansion is proposed. GM(1,N) is used to establish a regional energy consumption prediction model followed by energy consumption prediction in Henan Province of China. The application of case prediction is given. The analysis is performed. The results show urban expansion of the city's enormous influence energy consumption. Urban expansion should consider the bearing capacity of urban and social resources.

ACKNOWLEDGMENT

This research is sponsored by National Nature Science Foundation of China (No. 71001082).

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