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A Coordination Research on Urban Ecosystem in Beijing with Weighted Grey Correlation Analysis Based on Dea

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Abstract: Data Envelopment Analysis (DEA) and weighted grey correlation have been combined to establish an evaluation system from the perspective of input and output for the coordination of urban ecosystem. Data of Beijing between 2003 and 2010 have been adopted to evaluate and catalogue various styles of urban ecosystem in Beijing. The developing trends and existing problems of Beijing ecosystem are depicted, with the result that Beijing has experienced fluctuation of its ecosystem coordinated index in the span. The year of 2007 has witnessed the best coordination and the year of 2004 the worst, leaving the lesson that the constant growth of power and water consumption should be of primary concern for a target of sustainable economic development.

Key words: Data envelopment analysis, grey correlation analysis, urban ecological system

INTRODUCTION

It is an inevitable trend in research to regard the city as ecosystem caused by mutual intersection between modern ecology and urban science. Urban ecosystem is defined as the complex human ecosystem as a new term which includes the population, the urban secondary natural elements, natural resources and labor material elements and spiritual elements. A precise evaluation of urban ecosystem is of great significance in guiding the direction of urban development and implementing the sustainable urban development strategies. The recently economic development has brought urban ecosystem a lot of pressure in Beijing, for example, the appearance of fine particulate matter (referred to as PM2.5) which has become the hot spot of public discussion, resulting in a tremendous negative impact on travel, health of citizens and economic development, therefore it is important for sustainable development of the city in the future to make a scientific evaluation of the development situation of Beijing urban ecosystem.

There are many studies on eco-efficiency and ecosystem health at home and abroad (Chen *et al*., 2010; Xu and Zhang, 2006; Zhang *et al*., 2007), but the research methods are mainly confined to the DEA and Analytical Hierarchy Process (referred to as AHP) in these studies. For example, Yang (2009) and Xu (2010) has analyzed the regional eco-efficiency with the use of DEA, Ke and Li (2005) has studied the relationship among the resources, environment and economic development in various regions of China. However, the research method applied in these studies are still relatively monotonous and lack of innovation. For that reason, a better method-weighted gray correlation analysis based on DEA has been introduced in this study to Beijing urban ecosystem coordination. This method has two advantages over DEA and AHP separately. It not only has a simpler evaluation process than AHP but also can overcome the ordering problem of DEA when the decision-making units are all efficient. Beijing urban ecosystem development of coordination from 2003 to 2010 can been analyzed by using this study method in order to find out the problems that exist in Beijing urban ecosystem development process and propose rational and effective policy measures to provide the basis for construction of Beijing ecological city.

METHODOLOGY

Establish research index system: It is a prerequisite for complex integrated urban ecosystem assessment to establish an evaluation index system. Since it is the inherent requirement for the construction of ecological city to achieve balanced development among the resources, environment and economics, the urban ecosystem indicators this article used are divided into three kinds: Resource consumption, environmental pollution and economic growth indicators. Among these three kinds of index, the first two kinds measure the input situation and the third one is output indicators. There is a relationship of mutual interaction, restraint, interdependence existing in these three indexes, for

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Table 1: Indicator frame of urban ecosystem assessment

Level one indicator	Level two indicator	Specific indicator's form
Input indicators	Categories of indicators of resource consumption	Total energy consumption (Ten thousand tons of standard coal)/Index 1
		Total electricity consumption (One hundred million kilowatt hour)/Index 2
		Total water(One hundred million cubic meters)/Index 3
	Categories of indicators of environmental pollution	Industrial wastewater emissions (Ten thousand tons)/Index 4
		Industrial waste gas emissions (One hundred million Cubic meter)/Index 5
		Industrial solid waste generation (Ten thousand tons)/Index 6
Output indicators	Categories of indicators of economic growth	GDP(One hundred million yuan)/Index 7

example, resource consumption and environmental pollution index there can reflect investment efforts for economic development as well as the extent of the affected by economic development.

The resource consumption situation has been depicted by the total energy, electricity and water consumption while the environmental pollution situation has been measured from industrial wastewater release, industrial waste gas emission and industrial solid waste generation three aspects. Since economic growth indicator in this study is mainly to reflect the level of economic output, the gross domestic product is specifically chosen to represent it. The seven indexes constitute a complex urban ecosystem evaluation system together. Index system is shown in Table 1.

Choose study method: Subjectivity exists in determining of weights in gray relational analysis and once the weights are determined they will be applied to the correlation calculations of all the factors, so this weight belongs to the "homogenization" weighting. At the same time, the DEA analysis can only evaluate whether the unit is efficient, but the effective unit cannot be ordered. Based on that, weighted gray relational analysis based on DEA has been adopted in this study to synthesize advantages and avoid disadvantages of the two methods mentioned above.

Gray correlation analysis and DEA are integrated again in this study to shape a framework of weighted gray correlation analysis method based on DEA for urban ecosystem. There are aspects of work to be done to apply this method smoothly. First, the correlation coefficient e_{ik} should be calculated to measure the correlation between the optimal index and each index. The specific steps are as follows: the optimal value of each index must be selected to determine the optimal index set Y_0; Dimensionless processing should be carried out for every index values. If the index value is all objective value, it is better to select the mean dimensionless for comprehensive evaluation (Ye, 2003). According to this regulation, this study apply the formula $X_i = Y_i \div \overline{Y}(i = 0,1,2,\cdots,8)$ ($\overline{Y}$ represents the average of all the indicators for each year; i = 1, 2,…,) to carry on dimensionless processing; The differencing sequence should be calculated. In accordance with the formula $|X_0-X_i|$ (i = 1, 2,…, 8), differencing sequence can be solved out respectively, then the minimum and maximum values must be found out among all the differencing sequence and can be expressed as Δmin and Δmax; Correlation coefficient can be calculated by using the formula:

$$e_{ik} = \frac{\Delta\min + \rho\Delta\max}{|X_{0k} - X_{ik}| + \rho\Delta\max}$$

($\rho = 0.5$), e_{ik} represents the correlation coefficient between index k of sub-factor i and the index i of optimal index set. Secondly, the correlation coefficient between sub-factor i and the optimal index set should be calculated with the use of linear programming derived from DEA model, in which the weights should be regarded as a decision variable to avoid homogenization weighting. Specific models are as follows:

$$\max \theta = \sum_{k=1}^{7} w_k e_{ik} \tag{1}$$

$$\text{s.t.} \begin{cases} \sum_{k=1}^{7} w_k e_{ik} \le 1 (i = 1, 2, \ldots, 8) \\ \sum_{k=1}^{7} w_k = 1 \end{cases} \tag{2}$$

where, θ is the optimal connection degree between index i and optimal index set and w_k is the weight of index k. Eight correlation coefficients between eight factors and optimal index set will be calculated after repeating this DEA model for eight times.

The greater the θ is, the greater the correlation between the sub-factors and the optimal index set is in this article and the greater correlation means that the input is less while the output is larger, in other word, the urban ecosystem development at this time is more coordinate according to the selection criteria of optimal index set. Therefore, the optimal correlation coefficient can be defined as the coordination degree of urban ecosystem development.

BEIJING URBAN ECOSYSYTEM COORDINATION DEGREE EVALUATION

Data sources: The data related to this article are government statistics which has authority and recognized by the public. The data of the index 1 and index 2 of

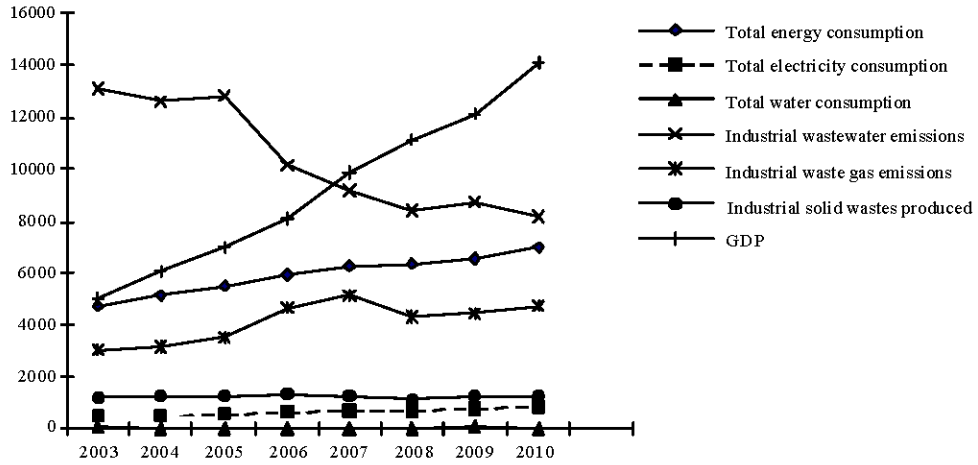

Fig. 1: Beijing urban ecosystem trends of individual indicators

Table 2: Value of indexes

Time	Index 1	Index 2	Index 3	Index 4	Index 5	Index 6	Index 7
2003(Y_1)	4708	461	35.8	13107	3005	1186	5007
2004(Y_2)	5140	510	34.6	12617	3198	1303	6033
2005(Y_3)	5522	567	34.5	12813	3532	1238	6970
2006(Y_4)	5904.	619	34.3	10170	4641	1356	8118
2007(Y_5)	6285.	675	34.8	9134	5146	1275	9847
2008(Y_6)	6327.	708	35.1	8367	4316	1157	11115.
2009(Y_7)	6570.	759	35.5	8713	4408	1242	12153.
Y_0	4708	461	34.3	8198	3005	1157	14114

Table 3: Optimal correlation of Beijing urban ecosystem

Year	2003	2004	2005	2006	2007	2008	2009	2010
Correlation	0.998344	0.816433	0.999683	0.999778	0.999935	0.9999	0.999735	0.999173

resource consumption are from the 2004-2011 "China Statistical Yearbook" and the data of index 3 of resource consumption are from 2004-2011 "Beijing Statistical Yearbook". The data of three indexes of environmental pollution are from the 2004-2011 "China environment Statistical Yearbook". The data of last indicators of economic growth are derived from 2004-2011 "China statistical Yearbook". Table 2 shows the 2003-2010 actual indicators' value of Beijing.

Evaluation results: Firstly, according to the calculation steps, correlation coefficient between each index and the optimal index set will be calculated, then 56 correlations will be produced. Secondly, with the use of EXCEL software here, the linear programming consistent with the constraints in DEA model can be carried out to solve the optimal correlation which is a integrated value representing the best correlation between seven indexes of every year with the optimal index set. The integrated coordination coefficient of urban ecosystem development during eight years can be calculated after eight times repeating of calculation process. The specific results are shown as Table 3.

According to the calculation results of optimal correlation in Table 3, some information can be learned. First, Beijing urban ecosystem coordination can be ordered in descending: 2007>2008>2006>2009>2005 >2010>2003>2004. Second, the average level of Beijing urban ecosystem coordination is 0.9766. Third, during these eight years, the coordination in every year is relatively similar, above 0.99, except for in 2004. Table 3 shows that: The seven indexes that impact the coordination of Beijing urban ecosystem have experienced different developpment trends during 2003-2010 periods. Total water usage and industrial solid waste generation are relatively stable compared with the relatively high-growth of GDP among these seven indexes. While the industrial waste gas emissions, total energy and electricity consumption have shown a trend of slow growth. At the same time industrial wastewater discharge is the only one index that continues to decline.

According to Fig. 1, the coordination of Beijing's urban ecosystem development has presented a process of fluctuation during 2003-2010. The coordination rearched the lowest level in 2004,and then hit the optimal degree in 2007. Beijing's urban ecosystem coordination has been

continually higher than the average of 8 years' level and the fluctuations of coordination is very small from 2005.

RESULTS AND DISCUSSION

Combined Fig. 1 and Table 3, three points can be deduced as follows.

First, the principle of selecting the optimal index set in this article is that the smaller input indicators value is the better and the bigger output indicators value is the better, therefore a higher optimal correlation (namely coordination) between the index set of every year and the optimal index set means the less input and lager output. According to the index system in this study, the reasons for lower Beijing urban ecosystem coordination can be attributed to these three points: too much consumption of resources, more serious environmental pollution or smaller economic output.

Second, the reason for the optimal coordination of Beijing urban ecosystem development in 2007 lies in the rapid growth of GDP and industrial wastewater emissions reduction tremendously. While compared with 2007, the reason for the lowest coordination in 2003 mainly because of too large industrial wastewater discharge, besides the regional GDP is too small, for example, the industrial wastewater release in 2003 is 43.5% more than that in 2007, but GDP only account for 50.84% of that in 2007. Then the rate of economic growth is less than the rate of environmental pollution increase in 2004, resulting in the lower urban ecosystem coordination than 2003. The coordination of Beijing urban ecosystem during 2005-2006 has gone up while the larger industrial wastewater release leaded to a lower coordination than that in 2007.

Third, a high speed growing GDP and a lower industrial wastewater release than that in 2007 did not make a higher coordination during 2008-2010 periods, because the total energy, electricity and water consumption stood a higher level than those in 2007. At the same time the continual growth of total energy and total electricity consumption kind of leaded to the decline trend of urban ecosystem coordination during these three years.

CONCLUSION

The coordination of Beijing urban ecosystem has showed a dynamic development process during 2003-2010. By comparing and analyzing the development changes of Beijing urban ecosystem coordination, the reason attributed to the continual reduction of Beijing urban ecosystem development coordination during 2008-2010 can be concluded as the following three aspects: The continued growth of total energy consumption and total electricity consumption and at same time the total water usage can be also further reduced.

Beijing issued a series of consecutive Policy Act in 2011 In order to improve the increasingly prominent problem of urban ecosystem coordinated development, including: « comprehensive energy conservation program of work during " the Twelfth Five"» «the State Council on Strengthening Environmental Protection Key work» «National groundwater Pollution prevention Plan (2011-2020)» «"the Twelfth Five" national environmental regulations and environmental economic policy construction planning» and so on. It is obvious that only energy consumption has been mentioned in these bills and no relevant policy has been introduced to deal with the growth problem of water and electricity consumption. On the contrary, NDRC issued a «national Development and Reform Commission office Hall on notice of doing related work to equal the price of electricity, water between business and industry» in 2009 to stimulate GDP growth and withstand the global financial crisis. The promulgation of this notification has lead to a further increase of the electricity consumption among commercial enterprises in Beijing where the same price of water between business and industry has already achieved for a long time. It is suggested that what costs on urban ecosystem coordination must be taken into account at the same time in order to achieve the continual growth of economics in Beijing.

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