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Efficiency evaluation and optimization of sustainable development of mining cities

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ABSTRACT

How to promote the sustainable development of mining cities has become a major problem which has to be solved urgently. However, due to regional differences, the mining cities are different in their degrees of sustainable development. Therefore, it has become necessary to make efficiency evaluation and optimization for the degrees of the cities' sustainable development. Currently there is less study on the efficiency evaluation of the sustainable development of the mining cities in China. In this paper, DEA method is used to research the efficiency evaluation and optimization of the sustainable development of the mining cities which is a supplement for the quantitative study in this field. This analysis and evaluation model overcomes the weakness of strong subjectivity of the commonly-used evaluation methods, therefore, the evaluation results are in accord with the practical situation of China.

KEYWORDS

Mining cities; Sustainable development; Efficiency evaluation; Efficiency optimization.

INTRODUCTION

Mining cities are one of the important city groups. They have rich mineral resources, continue to grow stronger when people explore, develop and build such natural endowment and finally form a single business-based pattern of urban management. Therefore, mining cities play an important role in our economic development and their uniqueness lies in their capacity to provide large amount of energies, industrial materials and agricultural means of production to the society through development of mineral resources and their effect of driving and radiation on the development of regional economy and relevant industries, rather than their contributions to politics, economy and cultural undertaking. And more importantly, the significant difference between the mining cities and general cities lies in the appreciable impact of the mining industry of the former on the rise and decline of a city. For example, under the influence of global economic crisis, the society has less demand for mineral resources and the price of the resources also declines constantly, so that the development of mining cities has been in a difficult situation. To promote the sustainable development of the mining cities and make them continue to provide resources to the society based on existing resource endowment has become a major issue to be solved now. From this perspective, in this paper, sustainable development of the mining cities is analyzed, bottleneck of such cities in sustainable development is checked and their efficiency in sustainable development has been evaluated and optimized, and finally several alternative means for their sustainable development are given from multiple levels, in order to provide reference information to the development of mining cities through this paper.

COMMENT OF LITERATURE

In the last decade, the sustainable development of mining cities has been paid more and more attentions, which not only concerns energy consumption and energy supply of mining cities and directly affects the development prospect of economic society. On this basis, many scholars have studied the sustainable development of mining cities from different perspectives and levels and have made many valuable conclusions[1-15]. Long Ruyin and Zhou Dequn (2003) analyzed the structure and features of the sustainable development of such cities from the perspective of sustainable development and system theory of mining cities and centrally discussed the coordination between the system and subsystem of sustainable development of mining cities, the regulatory mechanism of sustainable development and other problems, all such works they carried out have provided valuable decision-making bases to sustainable development of mining cities; Wang Zaihua (2004) firstly analyzed the general development of mining cities, then respectively explained basic concept and development stages of such cities, proposed various conditions for sustainable development after analyzing the main problems that the mining cities face in development and finally gave the principle, reference model and relevant countermeasures and suggestions for sustainable development of mining cities, which have high application value and lay a solid foundation for later study; Ju Songtao et al., based on the object of study Fushun, described and analyzed mineral resources, industrial structure, energy consumption, ecological environmental protection and other issues of mining cities and proposed the approach and countermeasures to promote the resources-based mining cities to make ecological re-structuring; Chen Fengmin, Xie Wuming and Liu Jingyong et al. (2005, 2009) started with the problems existing in the development of mining cities, systematically analyzed current development difficulties and the reasons of such difficulties, proposed the means to the mining cities for getting rid of development difficulties from many perspectives and suggested to make sustainable development for the mining cities by adjusting and optimizing industrial structure, developing alternative industries and energies and strengthening the awareness of ecological environment protection, etc.; Wei Fang and Xing Huaixue (2007), from the perspective of the current development of mining cities, comprehensively analyzed single industrial structure, insufficient backup resources, environment pollution and other problems in the development of mining cities and then on this basis proposed relevant suggestion to the mining cities for sustainable development from industrial structure, development pattern, environment protection and other steps; Song Yazhou, Han Baoping (2007) calculated and compared the ecological footprint of five mining cities in Xuhuai region in 2005 from the perspective of quantitative analysis and with "ecological footprint model" and the analysis results showed: in terms of per capita ecological footprint demand of mining cities, all objects studied exceeded the national average, the degree of ecological overload is Zao Village>Huainan>Huaibei>Jining>Xuzhou, showing that economic and social development of such cities have started to consume their own capital stocks and have posed serious threats to sustainable development of such cities; Gu Kangkang, Liu Jingshuang, Dou Jingxin (2008) also studied the mining cities in the central region of Liaoning Province with ecological footprint model, coupled ecological footprint and comprehensive ecological capacity indicator with "pressure-state-response model" and evaluated the comprehensive ecological capacity of the mining cities in this region from 1985 to 2005; Lu Yuhong, Tian Guie and Gu Feng (2009), starting with the complex ecosystem of mining cities, built the indicator system for ecosystem health assessment of mining cities and then evaluated current ecosystem health situation of 20 mining cities in China with comprehensive indicator evaluation model, and on this basis, partly explained and revealed the bottleneck of ecosystem health and development of the mining cities; Qiu Fangdao, Li Bo and Tong Lianjun (2009) applied MFA and data envelopment analysis model to the evaluation of the sustainable development of 14 mining cities, discussed evolution characteristics and relevant influence factors of the sustainable development capacity of such cities and made some valuable conclusions; however, in the opinion of Xu Lianlong (2010), the theory of sustainable development has become (must become) the only theoretical guidance for the development of mining cities, and the solution is just to make industrial transformation for such cities under the guidance of the theory; Xiang Jingwei (2010) designed the indicator system of sustainable development capacity of mining cities with principal component method, analytic hierarchy process, fuzzy comprehensive evaluation and other tools and made clustering analysis on mining cities based on the composite indicator; Wang Bangjun, Yang Dongtao and Zhou Min (2010) systematically analyzed the growth and development track of mining

cities on the background of Logistic dynamical model and drew an important conclusion that "building diversified industrial structure to wean the mining cities from their dependency on pure industry and achieve sustainable development" after simulating the different developmental stages of the mining cities.

It may be drawn from the above literatures that sustainable development of mining cities is an important historical proposition and topic of the times and shall be judged deeply, systematically and comprehensively. All works included in this paper are made to study both the efficiency evaluation and optimization of sustainable development of mining cities with DEA method based on existing studies and are an supplement to quantitative study of this field of study.

SUSTAINABLE DEVELOPMENT OF MINING CITIES AND ANALYSIS OF ITS BOTTLENECK

Analysis of sustainable development of mining cities

Under the double pressure of non-renewal of mineral resources and the pressure of economics and environment on the survival of mankind, the theory of sustainable development has become a new model of the development of mining cities (or even the only one model), and under the guidance of this theory, population, resources and environment, economy and other aspects of mining cities will get an opportunity to make long-term and healthy development. In the opinion of the former Prime Minister of Norway Mr. Brundtland, sustainable development is a concept of future, which includes some contents that the satisfaction of the needs of contemporary people shall pose any threat to the needs of future generations and the satisfaction of the needs of any social group (organization) shall not pose any hazard to other groups (organization)[16]. Therefore, for mining cities, their development and operation shall meet the needs of mankind and shall also protect natural environment to the utmost and not affect the nature to support the survival of contemporary people and future generations. From this perspective, sustainable development of wild cities shall ensure coordination of society, economy and environment, only then can sustainable development of cities and the mankind be achieved. It can be drawn that in the sustainable development of mining cities, more attentions shall be paid to the following contents, i.e. sustainable development of the society, sustainable progress of economy and sustainable utilization of environment.

Bottleneck of sustainable development of mining cities

Mining cities have the following features: high dependency on mineral resources and the critical influence of rise & fall of mining enterprises on urban development, single industrial structure of cities and disperse space structure, etc., therefore, in addition to providing enough power to the development of the mining cities, based on historical and practical conditions, mineral resources may also bring a lot of problems to urban development, especially when mineral resources and relevant industries and enterprises are confronted with the bottleneck of development, mining cities will be also in a dilemma of development. For example, most mining cities in China were built and gradually developed depending on a mine after state founding, though this model can better serve mining industry, it may also result in low urbanization level, industrial concentration, single urban function and poor extensionality, etc.; in the operation of mining cities, "the mainstay of the city" ——The contradiction of system functionality, proportion of dominant industry and alternative industries, the competition between state-owned mechanism and private mechanism and the paradox between technological improvement and employment, etc. may occur between the mining cities and the government and affect the sustainable development of mining cities[17]; in addition, because our overall economic development model still has not gotten rid of the high consumption, some energy-intensive heavy industry projects, which run counter to the sustainable development of the cities, are carried out in mining cities for better development and rapid progress and thus result in an extremely low proportion of light industry, primary industry and tertiary industry and lagged development of mining cities.

It may be drawn from the above analysis that after the impact of the industrial civilization in the world, ecological civilization and ecological civilization-based sustainable development framework is becoming a proper guidance for survival and development of the mining cities. Therefore, it is necessary to comprehensively evaluate the sustainable development and development efficiency of the mining cities, find some problems, seek for improvement approach and scale, put the development of mining cities to the development of general cities and make the sustainable development of mining cities contribute resources, energies and power to the sustainable development of the human society.

EFFICIENCY EVALUATION AND OPTIMIZATION OF SUSTAINABLE DEVELOPMENT OF MINING CITIES ——SAMPLE-BASED ANALYSIS AND SIMULATION

In order to evaluate and optimize the efficiency of the sustainable development of mining cities in the ecological innovation field, in this paper, DEA (data envelopment analysis) is used as an analysis tool to complete the following work:

Building of production possibility set

Supposing n mining cities are to be evaluated and the efficiency of their sustainable development will be evaluated comprehensively. Where: m_j th input indicator and s_j th of output indicator of j^{th} mining city DMU_j are respectively:

$$\boldsymbol{x}_j = (x_{1j}, x_{2j}, \cdots, x_{m_j j})^{\mathrm{T}}, \boldsymbol{y}_j = (y_{1j}, y_{2j}, \cdots, y_{s_j j})^{\mathrm{T}}, (\boldsymbol{x}_j, \boldsymbol{y}_j) > \boldsymbol{0}, j = 1, 2, \cdots, n$$

When examining whether the development of a mining city is effective or not, it is generally required to choose an "excellent" mining city as a reference and find the deficiency of mining city in its sustainable development by comparison.

Therefore, then supposing $\overline{n}$ "excellent" mining cities are sample units, and their input and output indicators are respectively represented with $\overline{\boldsymbol{x}}_j, \overline{\boldsymbol{y}}_j, (\overline{\boldsymbol{x}}_j, \overline{\boldsymbol{y}}_j) > \boldsymbol{0}, j = 1, 2, \cdots, \overline{n}$.

Meanwhile, define $T^* = \{(\overline{\boldsymbol{x}}_j, \overline{\boldsymbol{y}}_j) \mid j = 1, 2, \cdots, \overline{n}\}$ as the sample unit set, i.e. the set of "sample cities".

Based on data envelopment analysis[18], the production possibility set of the sample $\overline{T}$ may be built as:

$$\overline{T} = \left\{ (\boldsymbol{x}, \boldsymbol{y}) \left| \sum_{j=1}^{\overline{n}} \overline{\boldsymbol{x}}_j \lambda_j \leqq \boldsymbol{x}, \sum_{j=1}^{\overline{n}} \overline{\boldsymbol{y}}_j \lambda_j \geqq \boldsymbol{y}, \delta_1 (\sum_{j=1}^{\overline{n}} \lambda_j - \delta_2 (-1)^{\delta_3} \lambda_0) = \delta_1, \boldsymbol{\lambda} = (\lambda_0, \lambda_1, \cdots, \lambda_{\overline{n}})^{\mathrm{T}} \geqq 0 \right. \right\}$$

Where: $\delta_1, \delta_2, \delta_3$ are set 0 or 1.

Evaluation model of sustainable development of mining cities

By respecting setting input and output of j_0th mining cities $\mathrm{DMU}_j^{i_0}$ as $(f_j^{i_0}, g_j^{i_0})$, the following definitions may be made:

Definition 1 If $(\boldsymbol{x}, \boldsymbol{y}) \in \overline{T}$ does not exist, set $\boldsymbol{x} \leq f_j^{i_0}, \boldsymbol{y} \geq g_j^{i_0}$ and at least one inequation is established strictly, the development of j_0th mining city $\mathrm{DMU}_j^{i_0}$ is effective compared with sample city, otherwise, its development is ineffective.

For multi-objective programming model:

$$(D_{\mathrm{DMU}_j^{i_0}}) \begin{cases} \min \theta = V_{\mathrm{DMU}_j^{i_0}} \\ s.t. \ \sum_{j=1}^{\overline{n}} \overline{\boldsymbol{x}}_j \lambda_j \leq (\theta - \lambda_{\overline{n}+1}) f_j^{i_0} \\ \quad \sum_{j=1}^{\overline{n}} \overline{\boldsymbol{y}}_j \lambda_j \geq (1 - \lambda_{\overline{n}+1}) g_j^{i_0} \\ \quad \delta_1 (\sum_{j=1}^{\overline{n}+1} \lambda_j - \delta_2 (-1)^{\delta_3} \lambda_0) = \delta_1 \\ \quad \lambda_j \geq 0, j = 0, 1, \cdots, \overline{n} + 1 \end{cases}$$

There are following "Sufficient and Necessary" propositions.

Theorem 1 If the optimal value of the above plan is 1 and $\sum_{j=1}^{\overline{n}} \overline{\boldsymbol{x}}_j \lambda_j^0 = (\theta^0 - \lambda_{\overline{n}+1}^0) f_j^{i_0}, \sum_{j=1}^{\overline{n}} \overline{\boldsymbol{y}}_j \lambda_j^0 = (1 - \lambda_{\overline{n}+1}^0) g_j^{i_0}$, when and only when the development of j_0th mining city $\mathrm{DMU}_j^{i_0}$ is effective.

Optimized analysis of sustainable development of mining cities

After evaluation of the efficiency of sustainable development of the mining cities, the development efficiency of some cities may be in an ineffective state, thus their development efficiency shall be optimized in order to better promote their development towards a sustainable direction.

For multi-objective programming below:

$$(D_{\mathrm{DMU}_j^{i_0}}^{\varepsilon}) \begin{cases} \max(\overline{\boldsymbol{e}}^{\mathrm{T}} \boldsymbol{s}^- + \boldsymbol{e}^{\mathrm{T}} \boldsymbol{s}^+) = V_{\varepsilon} \\ s.t. \ \sum_{j=1}^{\overline{n}} \overline{\boldsymbol{x}}_j \lambda_j + \boldsymbol{s}^- = (1 - \lambda_{\overline{n}+1}) f_j^{i_0} \\ \quad \sum_{j=1}^{\overline{n}} \overline{\boldsymbol{y}}_j \lambda_j - \boldsymbol{s}^+ = (1 - \lambda_{\overline{n}+1}) g_j^{i_0} \\ \quad \delta_1 (\sum_{j=1}^{\overline{n}+1} \lambda_j - \delta_2 (-1)^{\delta_3} \lambda_0) = \delta_1 \\ \quad \lambda_j \geq 0, j = 0, 1, \cdots, \overline{n} + 1 \\ \quad \boldsymbol{s}^- \geq \boldsymbol{0}, \boldsymbol{s}^+ \geq \boldsymbol{0} \end{cases}$$

There are the following propositions:

Theorem 2 If $\mathrm{DMU}_j^{i_0}$ is ineffective compared with sample city, $(f_j^{i_0} - \boldsymbol{s}^{-0}, g_j^{i_0} + \boldsymbol{s}^{+0})$ is effective compared with $(\overline{\boldsymbol{x}}_j, \overline{\boldsymbol{y}}_j)$.

Application simulation

From systems theory and "input-output" theory, the efficiency of sustainable development of the mining cities are directly related to their system input and output, if a city can make minimum investment based on a given level of output, or make maximum output based on a given level of input, then it shows that the city has a relatively high efficiency in sustainable development, and even has an effective development. Supposing the efficiency evaluation of sustainable development is made for nine mining cities, in order to obtain a more realistic and "reference" evaluation results, it is required to continue to select three "excellent" mining cities as reference samples. Input indicators shall be selected as ten-thousand-yuan GDP energy consumption (t standard coal), per capita investment in fixed assets (ten thousand yuan), ratio of pollution control investment to GDP and output indicators shall be selected as comprehensive utilization rate of mining waste and recovery rate of destroyed mine land. Relevant data are as shown in TABLE 1.

TABLE 1 : Input - output indicators of sustainable development efficiency of mining city

DMU	Input			Output	
	Ten-thousand-yuan GDP energy consumption (t standard coal)	Per capita investment in fixed assets (ten thousand yuan)	Ratio of pollution control investment to GDP	Comprehensive utilization rate of mining waste	Recovery rate of destroyed mine land
Sample 1	0.56	3.09	0.15	0.65	0.72
Sample 2	0.34	2.56	0.19	0.76	0.87
Sample 3	0.51	3.33	0.17	0.77	0.83
DMU1	0.72	4.98	0.22	0.54	0.34
DMU2	0.67	5.33	0.31	0.56	0.31
DMU3	0.55	6.00	0.19	0.34	0.57
DMU4	0.37	3.36	0.19	0.79	0.65
DMU5	0.69	4.16	0.23	0.35	0.61
DMU6	0.68	5.43	0.26	0.60	0.30
DMU7	0.46	3.07	0.17	0.64	0.73
DMU8	0.81	5.36	0.20	0.48	0.48
DMU9	0.83	3.56	0.21	0.41	0.51

Source of sample data: China City Statistical Yearbook (2007-2012). Some data are collected based on calculation.

Analysis of simulation result

After evaluating the above data with $(D_{\mathrm{DMU}_j^{i0}})$ （$\delta_1 = 0$） model, the following results are obtained:

TABLE 2 : Results of evaluation

DMU	θ	Input redundancy (-)			Output redundancy (+)	
		Ten-thousand-yuan GDP energy consumption (t standard coal)	Per capita investment in fixed assets (ten thousand yuan)	Ratio of pollution control investment to GDP	Comprehensive utilization rate of mining waste	Recovery rate of destroyed mine land
DMU1	0.96	0.00	1.09	0.08	0.15	0.11
DMU2	0.67	0.13	1.23	0.01	0.09	0.03
DMU3	0.32	0.22	0.00	0.06	0.12	0.00
DMU4	0.34	0.00	0.00	0.00	0.00	0.00
DMU5	0.48	0.00	0.77	0.17	0.00	0.00
DMU6	0.59	0.32	0.00	0.09	0.23	0.12
DMU7	0.98	0.00	0.00	0.00	0.00	0.00
DMU8	0.97	0.23	0.00	0.11	0.21	0.17
DMU9	0.18	0.19	1.38	0.10	0.20	0.08

From the above TABLE it may be drawn that in the 9 mining cities evaluated, the cities numbered 4 and 7 make effective sustainable development, their efficiency value are 1 and input and output redundancy are zero and their "development state" has reached "Pareto effective", therefore, their development is effective. Other mining cities are in ineffective development because of their non-zero efficiency value θ. For such cities, their input and output indicators could be further improved and the improvement scale shall be determined based on input and output redundancy. For example, for DMU3, the ten-thousand-yuan GDP energy consumption and the ratio of pollution control investment to GDP shall be respectively decreased by 0.22 and 0.06, and comprehensive utilization rate of mining waste shall be increased by 0.12, so that the sustainable development efficiency of such mining cities will be effective.

POLICY SUGGESTIONS ON SUSTAINABLE DEVELOPMENT OF MINING CITIES

Through the above analysis, it may be drawn that for mining cities, the driving force for their sustainable development lies in: in case of a given output, sufficiently reducing energy consumption, per capita investment in fixed assets and the ratio of pollution control investment to GDP, while in case of a given input, increasing the comprehensive utilization rate of mining waste and recovery rate of destroyed mine land, namely, reforming the capacity of the mining cities with get refined internally and externally. In order to achieve this, we believe that the following works shall be carried out simultaneously: (1) Fully excavate resource potential of mining cities. In order to achieve sustainable development of mining cities, deeply excavate the resource potential of mining cities and look for the backup resources for development and utilization. At the same time, achieve the "protect while developing and develop while protecting" mode for mineral resources, pay equal attention to both development and conservation, maximize resource utilization and strive to build competitiveness in new areas; (2) Build diversified development strategy and comprehensively develop alternative industries. Make industrial adjustment to mining companies in a planed and orderly way, follow connotative development road and timely transform industries and economy, in order to gradually develop a modern city of diversified development and continued prosperity. For example, make deep processing of mineral products, effectively extend the industrial chain, give more support to non-mining industry and transform single economic development pattern to comprehensive pattern; (3) Strengthen ecological and environmental protection through technical innovation. First, enhance the environmental awareness of urban residents and strengthen pollution control to the utmost through fund and technology investment in the resource development process, in particular, focus on cultivating high-tech industries with characteristics and make environmental management and ecological restoration so as to synchronize the development of society, economy and environment.

CONCLUSION

As an important member of the town cluster, sustainable development of mining cities is closely related to society, economy and environment. Therefore, it is necessary to actively promote the harmony between mankind and the nature, especially in current situation of unceasing worsening of human survival environment and increasing resource exhaustion, more attention shall be paid to and a consensus shall be reached for sustainable development. However, we need to see and anticipate that the decision made by the mining cities for short-term development with mineral resources under the influence of both history and reality factors will be fulfilled continuously, and more invisible factors also affect the development model of such cities. From this perspective, the sustainable development of mining cities is a complex and difficult process, anticipated development can only be achieved by taking the ecological innovation as a field, finding deficiency and looking for improvement measures and fulfilling them, and input and output shall be constantly adjusted and balanced.

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