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A DEA-Based Performance Evaluation of Ecological Land Development of Cities

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Abstract

Because of population clustering, the density of land use continues to increase in cities, which will drive up property prices and worsen the quality of living environments. Because of its natural environment, ecological land can provide a better environment for living and/or leisure. Moreover, with people paying more attention to leisure activities and more convenient urban-rural traffic, the development of ecological land has become an inevitable trend. In this study, the data envelopment analysis (DEA) method is used to evaluate the ecological land development efficiency of nine cities (DMUs) in Fujian Province, mainland China. According to the analysis results, it is found that one DMU is a robustly strong unit in terms of the ecological land development, three DMUs are marginal inefficient units, and the remaining five DMUs are significantly inefficient units. Moreover, through the sensitivity analysis, key influence factors of ecological land development in the city are analyzed and found. By conducting the DEA analysis with the exclusion of the input and output factors, the sensitivity of each factor to the efficiency value is measured. Based on the analysis results, suggestions are made in this study in the hope of providing helpful references for reasonable land development and sustainable development of the environment in the city.

Keywords: urban ecology, ecological land, eco-management, performance evaluation

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INTRODUCTION

Urban development in different generations faces different tasks and challenges with researchers proposing new and creative concepts and guiding the cities to develop in the appropriate direction. The proposal and development of concepts, such as sustainable development, ecological city, ecological modernization, and ecological state, reflect not only the requirements for new-generation environmental governance in the future but also the characteristic emphasis on ecological issues of the environmental governance in the present. In the recent discussions about urban development in response to the climate change and environmental issues around the globe, the concept of "ecological city" or "eco-city" has become an ideal goal with its emphasis on green technologies for residential buildings and application of wind power and solar power (Hsueh 2015, Liu 2017). This concept calls for full integration of technologies required for urban development and nature, arguing that human habitats should be built on not only the balance among society, economy and nature but also a benign cycle of ecosystems. However, there is no absolute standard or specific indicator that can measure and confirm the development of a city is indeed on the right track of becoming an eco-city. Many researchers have proposed different models and frameworks, such as ecological footprint, ecological system resource/service evaluation, ecological niche, and landscape pattern analysis, to evaluate the ecological sustainability and resource application of a city. Based on these methods, convenient tools will be developed to better evaluate, monitor and manage environmental governance.

However, because of population clustering, the density of land use continues to increase in cities, which will drive up property prices and worsen the quality of living environments. Because of its natural environment, ecological land can provide a better environment for living and/or leisure. Moreover, with people paying more attention to leisure activities and more convenient urban-rural traffic, the development of ecological land has become an inevitable trend. In this study, the data envelopment analysis (DEA) method is used to evaluate the ecological land development efficiency of nine cities (DMUs) in Fujian Province, mainland China. According to the analysis results, it is found that one DMU is a robustly strong unit in terms of the ecological land development, three DMUs are

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marginal inefficient units, and the remaining five DMUs are significantly inefficient units. Moreover, through the sensitivity analysis, key influence factors of ecological land development in the city are analyzed and found. By conducting the DEA analysis with the exclusion of the input and output factors, the sensitivity of each factor to the efficiency value is measured. Based on the analysis results, suggestions are made in this study in the hope of providing helpful references for reasonable land development and sustainable development of the environment in the city.

LITERATURE REVIEW

Land Use and Eco-development

Berzina et al. (2015) indicate land is an ecological totality. On the one hand, it provides a fundamental environment for the survival, living, and development of vegetation, animals, microorganisms, and humanity. On the other, it changes because of different levels of influences from the biological communities living on it. The interactions and mutual influences between an environment and the biological communities living in it constitute a land eco-system (Liu KS et al. 2018, Palliwoda et al. 2017). Speak et al. (2015) believe changes in land use will affect climate, water systems, storage and absorption of sequestrated carbon, and biodiversity. According to the research by Campbell et al. (2016), the biodiversity in a city is subject to the influences of the quantity, sizes, shapes, types, and distribution of green land in the city. With more green land serving as habitats for different creatures, the biodiversity in the city will increase. Therefore, diversity of habitats is the most decisive factor in maintaining biodiversity. Chang and Huang (2015) also point out that habitat maintenance is of great significance to biological conservation. Habitat diversity is the source of biodiversity potential; therefore, it is of great ecological values for a city to maintain habitat diversity. Eigenbrod (2016) indicates it is vital to maintain the functionality of habitat network in a city; however, it is never a priority concern for the city government lacks in sufficient information for biodiversity development. Hsueh and Su (2016, 2017) point out the importance of governmental policy and education for environmental protection.

Ecological Land Management and Evaluation

As indicated by Chang and Huang (2015), there are three measures of ecological land development and management: community participation, wetland management, and ecosystem management. According to Andersson et al. (2015), community participation is mainly realized through the self-governance and monitoring by community residents. Wetland management reflects the importance of wetland environments for ecological habitats and ecological systems. There are five treatment principles in ecosystem management: (1) respecting ecological evolution, including ecological cycle and diversity; (2) observing the ecological dimension from a long-term perspective; (3) applying scientific evaluation and analysis; (4) regarding humanity and the other creatures as part of the eco-system; and (5) adopting integrated solutions and measures. The above-mentioned "scientific evaluation and analysis" is the kind of development management mechanism that is rather lacking now. Phearson et al. (2014) indicate: all the existing strategies and results are at the end of the pipe. Land use development and technological interference can only result in minute responses from the environment. As suggested by Hung et al. (2016), what is needed now is a broader analysis framework to better understand the consumption of natural resources and enhance their values. This framework can help to solve problems of ecological damage caused by inappropriate land use and development (Swapan et al. 2017). Sutton and Anderson (2016) propose that ecological land management can help people and communities to use biodiversity and ecological system services as part of their strategies in response to the negative impacts from climate and environmental changes. They advocate that people should realize that an eco-system is composed of an abundant mixture of elements interacting with one another in a substantial manner.

Ecological Land Performance Evaluation Method

Several ecological land performance evaluation methods have been developed from the studies and suggestions by different researchers. There are two major categories of such methods: "per unit ecological resources" and "composite indicator" (Buchel and Frantzeskaki 2015). Methods of the first category directly use different kinds of units to calculate and compare ecological resources. For example, the "ecological footprint" method measures the area of land required to support the resource consumption and waste treatment in a city. The "ecological carrying capacity" method evaluates and compares the ecological volume a city can carry in different areas and time periods (Costanza et al. 2014). The "ecological value calculation" method evaluates the ecological values of all the land in a city based on the ecological value coefficient per unit of land. Methods of the second category use composite indicators to give an overall evaluation. The most representative method of the second category is the System of Integrated Environmental and Economic Accounting (SEEA) published by the UN Statistics Division. Using the method of green GDP accounting, SEEA can provide integrated environmental and economic evaluations and it has been modified several times based on the suggestions from various researchers (Ibes 2016). The Chinese government has recently developed the "Eco-city Overall Evaluation Index" and used the index to grade cities into different levels of ecological cities in order to promote the development of eco-cities and eco-tourism. Each evaluation method has its strengths, weakness, and conditional restraints in its application. Therefore, different evaluation methods will be used for different perspectives of ecological performance evaluation (Swapan et al. 2017).

RESEARCH DESIGN

Selection of Input and Output Factors

In the selection of input and output factors in this study, the modified Delphi method is used in this study by drawing references from literature review and directly developing a structural questionnaire survey for the first round of questionnaire survey. This method is time-saving and can help the participating specialists in this study to focus on the research topics without any need to conjecture as in answering an open questionnaire. Totally 32 questionnaires were distributed and 24 valid samples were collected with a return rate of around 75%. The source of data used for the factors in this study are all statistical data open to the public.

Variable Definition:

Input:

(1) Management Cost: all the costs incurred in the eco-management process.

Output:

(1) Land Area: The area of ecological land.

(2) Evaluation Indicator: Eco-city Overall Evaluation Index (hereinafter referred to as the "Evaluation Index")

Efficiency Evaluation Analysis Method

From the perspective of economics, when an entity produces more outputs with less inputs, it means the entity has better "performance". Performance can be measured using "efficiency" as the evaluation standard. Based on the comparison of inputs and outputs, efficiency can be defined as "the ratio of the sum of weighted outputs to the sum of weighted inputs." The function of maximum outputs obtained from different combinations of inputs is called "product function". Generally, the maximum outputs obtained from the inputs are no larger than the product function; therefore, product function is also called "production frontier". In the measurement of efficiency, the inputs and outputs of all the evaluated decision-making units (DMU) are projected onto a geometric space according to the theory of envelopment line to evaluate their relative efficiency and find out the efficiency surface that can envelope all the observed data to form the efficiency frontier. Then by calculating the distance between the data of each DMU and the enveloping efficiency surface, the relative efficiency value of each DMU is obtained.

The data envelopment analysis (DEA) method is used in this study as an efficiency evaluation tool. Different from the traditional regression analysis which finds the average path among a series of data points, DEA envelops the data of all samples and finds out the connections among them. It has the advantages that a good efficiency assessment model must have. Using the technology of linear development, this method considers all the factors that can be used to measure and compare the performance of each evaluated units that share similar characteristics.

EMPIRICAL ANALYSIS OF ECOLOGICAL LAND DEVELOPMENT PERFORMANCE

Analysis of Ecological Land Development Performance

By introducing all the input and output values of the nine cities in Fujian Province into the CCR and BCC models, the overall production efficiency and technology efficiency values of the cities are obtained. Then by dividing the overall production efficiency value with the technology efficiency value of each city, the scale efficiency value of each city was obtained. The analysis results are listed in **Table 1**.

As shown in **Table 1**, Xiamen's overall production efficiency value is equal to 1, indicating Xiamen is the most efficient in ecological land development among the nine cities. The overall production efficiency values of the other cities are relatively low with the value of Zhangzhou being the lowest. It is probably because this city failed to effectively use its input factors or failed to reach the optimal production scale. Further analysis is required to find out the actual reasons.

Table 1. Relative Ecological Land Development Efficiency Values of the DMUs

DMU	Overall Production Efficiency	Technology Efficiency	Scale Efficiency
Nanping	0.91	0.91	0.91
Longyan	0.88	0.88	0.88
Ningde	0.80	0.81	0.80
Putian	0.84	0.84	0.84
Xiamen	1.00	1.00	1.00
Fuzhou	0.96	0.94	0.98
Sanming	0.76	0.75	0.76
Quanzhou	0.98	0.98	0.98
Zhangzhou	0.72	0.71	0.72

Table 2. Sensitivity Analysis Results after the Exclusion of Input and Output Factors

DMU (City)	Original Efficiency Value	Excluding Management Cost	Excluding Land Area	Excluding Evaluation Index
Nanping	0.91	0.82	0.87	0.85
Longyan	0.88	0.80	0.81	0.82
Ningde	0.80	0.72	0.75	0.76
Putian	0.84	0.76	0.80	0.79
Xiamen	1.00	0.91	0.93	0.94
Fuzhou	0.96	0.89	0.90	0.92
Sanming	0.76	0.68	0.70	0.71
Quanzhou	0.98	0.91	0.92	0.94
Zhangzhou	0.72	0.63	0.67	0.68
Number of Efficient DMUs	1	0	0	0

Source: data compiled in this study

Sensitivity Analysis

The main purpose of this study is to find out and analyze the key influence factors of ecological land development in the city through sensitivity analysis. The input and output variables are excluded one at a time in the DEA analysis to find out its sensitivity to the efficiency value. The change rate of sensitivity is used as the basis for evaluation. The sensitivity factors are management cost, land area, land area, and evaluation indicator. As shown in **Table 2**:

(1) After the exclusion of "Management Cost", the efficiency values of all the DMUs are lower than their original values, indicating the factor of "Management Cost" is of relatively high importance to all the DMUs;

(2) After the exclusion of "Land Area", the efficiency values of all the DMUs are lower than their original values, indicating the factor of "Land Area" is of relatively high importance to all the DMUs; and

(3) After the exclusion of "Evaluation Index", the efficiency values of all the DMU are lower than their original values, indicating the factor of "Evaluation Index" is of relatively high importance to all the DMUs.

CONCLUSION

According to the DEA results, Xiamen has the highest ecological land development efficiency value at 1 (robustly strong unit level), accounting for 11% of all the DMUs. The ecological land development efficiency values of three other cities range from 0.9 to 1 (marginal inefficient unit level), accounting for 33% of all the DMUs. This finding suggests that it is easier to improve the ecological land development efficiency of these three cities. The ecological land development efficiency values of the remaining five DMUs are all lower than 0.9 (significantly inefficient unit level), accounting for 56% of all the DMUs. Among them, Zhangzhou has the lowest ecological land development efficiency. Xiamen's high ecological land development efficiency values can be attributed to the great efforts of the Xiamen Municipal Government and the Xiamen Municipal Council in environmental protection and ecological development. Occupying 1.3% of the land in Fujian Province, Xiamen accounts for 14% of the total output value, nearly 25% of the revenues, and 50% of the total import-export volume of the province. Ranking among the top in China in the environmental quality index evaluations, Xiamen is proactively fulfilling the concept of "green development", trying to achieve development without compromising the environment. With its green coverage rate in urban area already high at 43.62%, Xiamen is still increasing the ratio of its green spaces.

All these achievements come from Xiamen's investments in ecological restoration during the past years. Its ecological restoration of several bay areas, such as the Wuyuan Bay, Xinlin Bay, Maluan Bay and Dongkeng Bay areas, has helped to greatly expand the size of ecological land in Xiamen, creating new spaces for further development of the city. Xiamen has also implemented integrated ecological restoration of its nine minor river systems, mountains, forests, farmland, roads and villages to ensure a balance among economic development, social development and ecological development. The case of Xiamen exemplifies the importance of integrated planning and implementation of eco-management for all kinds of ecosystems in the city.

SUGGESTION

The following suggestions are made in this study for land development in an eco-city:

(1) More integrated land use/development management and more stringent land use control should be implemented. All the land use

activities should meet the requirements of the integrated land use/development management. The protection of agricultural land, in particular the basic farmland, should be strengthened while better control should be imposed on the land for construction in order to achieve good coordination in the use of land for production, living, and ecological development.

(2) More promotion of environmental protection should be implemented through school education and social education. In addition, environmental protection education among farmers should be strengthened in order to strike a balance between agricultural production and environmental protection and reduce the negative impacts from agricultural activities on the environment. Farmers in areas with poor conditions for agricultural production or with beautiful natural landscape should be encouraged to convert to extensive agriculture or cease agricultural production in order to ensure better conservation of the natural environment and landscape in these areas.

(3) The data about land use/management should be collected and updated regularly through both onsite measurements and remote measurements such as aerial photography while the data should be managed on computers. The standards of land use categorization should be developed to provide solid reference for land use.

(4) The protection of natural landscape and ecological environment should be strengthened in both urban and rural areas. Governments at all levels should not only strike a balance between natural landscape development and conservation but also promulgate related regulations to ensure proper implementation.

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