

Chengdu Plain Economic Zone Evaluation of Urban Land Use Eco-efficiency

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ABSTRACT

Objective of the study: to measure the eco-efficiency of urban land use in Chengdu Plain Economic Zone from 2012 to 2021 and conduct static analyses to eliminate the effects of external environmental variables and random disturbance terms. Research method—SBM model, Malmquist index model. Research results—the mean value of urban land use eco-efficiency in Chengdu Plain Economic Zone declines in the vast majority of time fluctuations without considering random errors and external environmental variables.

KEYWORDS

urban land use eco-efficiency; SBM model; Malmquist index model

"Building an ecological civilisation is a long-term plan for the well-being of the people and the future of the nation". Land use throughout the entire production and living process of human beings, the ecological efficiency of urban land use stems from land use eco-efficiency. Foreign land use eco-efficiency research started earlier, Wilkins^[1] that eco-efficiency focuses on the efficiency and sustainability of agricultural production and land management, the eco-efficiency of land use management needs to be constructed to improve the eco-efficiency of the high-complexity production system. Ehrenfeld^[2] eco-efficiency play a decision-making role in eco-efficiency needed to construct the eco-efficiency indicator signs and tools. Barba-Gutierrez et al.^[3] applied the data envelopment model (DEA) to analyse and evaluate the eco-efficiency from the perspective of input-output. The domestic land use eco-efficiency evaluation research started relatively late, Peng Jian et al.^[4] conducted a comprehensive evaluation of land use in Jiangning District, Nanjing by constructing a four-aspect land use efficiency evaluation index system of ecological, social, economic and environmental aspects, and using the hierarchical analysis method. Zhu Dajian and Qiu Shoufeng^[5] attempted to draw on the eco-efficiency indicators in the German environmental economic accounts and constructed eco-efficiency indicators suitable for measuring the development of China's circular economy according to the actual situation in China. Yan Zhang and Zhifeng Yang^[6] Establish a metric model for the eco-efficiency of urban material metabolism, and take Shenzhen City as an example to account for urban water, energy and waste metabolic fluxes as well as the eco-efficiency of metabolism. This paper summarises previous research results and defines urban land use eco-efficiency as the maximisation of urban land use value and minimisation of environmental costs to achieve optimal inputs and outputs while adhering to the premise of ecological priority.

1 Overview of the study area and data sources

1.1 Overview of the study area

The Chengdu Plain Economic Zone includes the cities of Chengdu, Deyang, Mianyang, Suining, Leshan, Ya'an, Meishan and Ziyang. The Chengdu Plain Economic Zone 14th Five-Year Plan for Integrated Development^[7] states that during the 14th Five-Year Plan period, it is necessary to further improve the quality of the ecological environment, establish a comprehensive mechanism for prevention and control of the ecological environment, effectively solve outstanding environmental problems, significantly enhance ecological governance capacity, basically form a green and low-carbon lifestyle and production mode, build an economically mature and ecologically sound economy, and develop a green and low-carbon lifestyle. It also states that the 14th Five-Year Plan period will further improve the quality of the ecological environment, establish a comprehensive prevention and control mechanism for the ecological environment, effectively solve outstanding environmental problems, significantly enhance the capacity for ecological governance, basically form a green and low-carbon lifestyle and mode of production, and build a modern metropolitan area with a mature economy, excellent ecology and a happy life.

1.2 Data sources

The data for the indicators in this paper come from China Urban Statistical Yearbook, Sichuan Statistical Yearbook, Chengdu Statistical Yearbook, Mianyang Statistical Yearbook, Ziyang Statistical Yearbook, Deyang Statistical Yearbook,

Meishan Statistical Yearbook, Leshan Statistical Yearbook, Suining Statistical Yearbook, and Ya'an Statistical Yearbook for the years from 2013 to 2022.

2 Indicator system construction and research methodology

2.1 Indicator system construction and research methodology

Based on the three major theoretical foundations of the theory of diminishing returns to land, the theory of sustainable development and the theory of sustainable development of land resources, this paper establishes an evaluation index system according to the principles of reasonableness, comprehensiveness and objectivity based on the eco-efficiency of land use as defined in this paper (see Table 1).

Table 1 Evaluation index system of urban land use eco-efficiency in Chengdu Plain Economic Zone

Type of indicator	Norm	Description of indicators
Input indicators	Natural resource inputs	Average land energy input/(t/hm ²)
		Total energy consumption/built-up land area
		Per capita water input/(m ³ /hm ²)
Social resource inputs		Total water consumption/built-up land area
		Average labour input per plot/(person/hm ²)
		Number of urban employees/area of built-up land
Output indicators	Expected outputs	GDP of per capita regional secondary and tertiary gross domestic product (million yuan/hm ²)
		Average wage of employed persons in all urban units (yuan)
		Greening coverage of built-up areas (%)
	Non-expected outputs	Total industrial sulphur dioxide emissions (t)
		Total industrial wastewater discharge (billion standard cubic metres)
environment variable		Total industrial fume (dust) emissions (million tonnes)
		Industrial structure (%)
		Ratio of tertiary sector to GDP Value
		Population density (10,000 persons/hm ²)
		Revenue from urban maintenance and construction tax (\$ million)

2.2 SBM 模型

The first stage of this method selects the SBM-Undesirable model proposed by Tone ^[8] in 2001, which can achieve a comprehensive and integrated comparative analysis of urban land use eco-efficiency of the cities in the Chengdu Plain Economic Zone, and its mathematical expression is shown below:

$$\min \rho = \frac{1 - \frac{1}{m} \sum_{i=1}^m \frac{s_i^-}{x_{i0}}}{1 + \frac{1}{s_1 + s_2} \left(\sum_{i=1}^{s_1} \frac{S_i^q}{y_{k0}^q} + \sum_{i=1}^{s_2} \frac{S_i^b}{y_{t0}^b} \right)}$$

Equation(1)

Subject to:

$$\begin{cases} x_{i0} = \sum_{j=1}^n x_{ij} \beta_j + s_i^- \\ y_{k0}^q = \sum_{j=1}^n y_{kj} \beta_j - s_i^q \\ y_{t0}^b = \sum_{j=1}^n y_{tj} \beta_j + s_i^b \\ \sum_{j=1}^n \beta_j = 1, s_i^- \geq 0, s_i^q \geq 0, s_i^b \geq 0, \beta_j \geq 0 \end{cases}$$

Equation (2)

In the formula, ρ denotes the eco-efficiency of urban land use, m denotes the input variable, S_1 denotes the number of desired outputs, and S_2 denotes the number of undesired outputs; β_j denotes the weight vector. x_{ij} denotes the i th input variable of the j th city, y_{kj} is the k th desired output variable of the j th city, and y_{tj} the t th non-desired output variable of the j th city.

2.3 Malmquist 指数模型

Since the SBM-Undesirable model could not reflect the dynamic changes, the Malmquist index analysis model was chosen to examine the evolutionary characteristics of the eco-efficiency of urban land in the cities of Chengdu Plain Economic Zone from 2012 to 2021. The expressions are as follows:

$$MI = EC \times TC$$

$$= \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \times \left[\frac{D^t(x^t, y^t)}{D^{t+1}(x^t, y^t)} \frac{D^t(x^{t+1}, y^{t+1})}{D^{t+1}(x^{t+1}, y^{t+1})} \right]^{\frac{1}{2}} \quad \text{Equation(3)}$$

In the formula, the Malmquist index (Total Factor Productivity MI) refers to the degree of productivity change of the cities in the Chengdu Plain Economic Zone from period t to period $t+1$; where $D^t(x^t, y^t)$ denotes the input distance function of the cities in the Chengdu Plain Economic Zone between period t and period $t+1$ when the technology of period t is taken as the reference, and $D^{t+1}(x^{t+1}, y^{t+1})$ denotes the input distance function of the cities in the Chengdu Plain Economic Zone between period t and period $t+1$ when the technology of period $t+1$ is taken as the reference. The input distance function of in period t and period $t+1$ when the technology in period $t+1$ is used as the reference. Total factor productivity (MI) can be decomposed into technical efficiency change index (EC) and technical change index (TC), and technical efficiency (EC) can be decomposed into pure technical efficiency (PEC) and scale efficiency (SEC). When $MI > 1$, total factor productivity is on an upward trend. When $EC > 1$, technical efficiency is improving; when $TC > 1$, technology is improving.

3 Empirical results and analyses

3.1 Analysis of Eco-efficiency Value of Urban Land Use in Chengdu Plain Economic Zone by City, 2012-2021

The data were incorporated into the SBM-Undesirable model to measure and evaluate the values of urban land use eco-efficiency of eight prefecture-level cities in the Chengdu Plain Economic Zone from 2012 to 2021 (Table 2). Longitudinally, the mean value of urban land use eco-efficiency in Chengdu Plain Economic Zone fluctuates and decreases in different years in the first stage, and is at the lowest value in 2015 and then at the highest value in 2016. The fluctuation is mainly due to the infinite expansion of urban land, but the capital and labour force have not grown simultaneously, and the degree of urban land use intensification has declined; at the same time, with the continuous advancement of industrialization, more and more factories have been built, and although the governmental agencies are vigorously pushing forward the construction of the "park city" and the integration of ecological environment, etc., it is still not possible to achieve a stable urban land use efficiency in Chengdu Plain Economic Zone. The average value of urban land use eco-efficiency in Chengdu Plain Economic Zone has been in a fluctuating state, but generally speaking, there is not much difference between 2021 and 2012. Horizontally, the average value of urban land use eco-efficiency of cities in Chengdu Plain Economic Zone is 1.187 without considering random errors and external environmental variables, and the efficiency values of the remaining seven cities except Chengdu are more obviously different from that of Chengdu.

Table 2 Eco-efficiency values of urban land use in the first stage of cities in Chengdu Plain Economic Zone, 2012-2021

City	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	average value
Chengdu	2.613	2.580	2.402	1.896	2.145	2.024	1.871	1.904	1.896	1.910	2.124
Deyang	1.054	1.107	1.149	1.026	1.042	1.012	1.046	1.080	1.141	1.134	1.079
Mianyang	1.088	1.105	1.109	1.145	1.090	1.167	1.191	1.095	1.011	1.057	1.106
Ziyang	1.088	1.107	1.126	1.171	1.160	1.238	1.314	1.418	1.588	1.483	1.269
Leshan	1.151	1.263	1.225	1.235	1.271	1.364	1.337	1.268	1.315	1.304	1.273
Meishan	1.148	1.032	1.011	1.019	1.051	0.869	0.782	1.010	1.058	0.537	0.952
Ya'an	0.180	0.206	0.262	0.266	0.688	0.615	0.608	1.013	1.001	1.002	0.584
Suining	1.190	1.180	1.196	1.081	1.152	1.086	1.074	1.029	1.048	1.040	1.108
average value	1.189	1.197	1.185	1.105	1.200	1.172	1.153	1.227	1.257	1.183	1.187

3.2 Average Malmquist Index and its Decomposition for Cities in Chengdu Plain Economic Zone by Year, 2012-2021

Subsequently, the dynamic change characteristics of urban land use eco-efficiency in the Chengdu Plain Economic Zone were further investigated by measuring the Malmquist Index (see Tables 3 and 4). Overall, the MI of the eight cities in the Chengdu Plain Economic Zone is 1.144 in 2012-2021, reaching the efficiency frontier surface, but the growth rate is only 14.4%, and the growth rate keeps fluctuating. Among them, the influence of TC on the improvement of urban land use eco-efficiency in the Chengdu Plain Economic Zone is greater than that of EC, with an average value of 1.140 and a growth rate of 14.0% for TC. EC can be further decomposed into PEC and SEC, and from Table 3, we can derive that the average value of PEC is 1.043, with a growth rate of only 4.3%, and that the average value of SEC is 1.001, with a growth rate of only 0.1%. This indicates that there are some differences in pure technical efficiency and scale efficiency in the Chengdu Plain Economic Zone, but both are low.

Table 3 Average Malmquist index and its decomposition in the first stage of cities in Chengdu Plain Economic Zone by year

Vintages	<i>MI</i>	<i>EC</i>	<i>TC</i>	<i>PEC</i>	<i>SEC</i>
2012-2013	1.118	1.000	1.118	0.958	1.062
2013-2014	1.085	0.997	1.087	1.066	0.947
2014-2015	1.109	0.983	1.134	0.935	1.072
2015-2016	1.301	1.055	1.247	1.022	1.037
2016-2017	1.181	1.008	1.172	1.036	0.995
2017-2018	1.270	0.943	1.371	1.141	0.865
2018-2019	1.086	1.229	0.921	1.108	1.144
2019-2020	1.074	0.958	1.135	0.978	0.968
2020-2021	1.075	1.000	1.075	1.144	0.923
average value	1.144	1.019	1.140	1.043	1.001

Table 4 Decomposition of urban land use eco-efficiency in the first stage of cities in Chengdu Plain Economic Zone, 2012-2021

City	<i>MI</i>	<i>EC</i>	<i>TC</i>	<i>PEC</i>	<i>SEC</i>
Chengdu	1.047	0.987	1.062	0.969	1.021
Deyang	1.215	1.038	1.176	1.005	1.032
Mianyang	1.092	0.997	1.097	0.990	1.008
Ziyang	1.112	1.037	1.070	1.292	0.855
Leshan	1.159	1.019	1.137	1.115	0.958
Meishan	1.246	1.042	1.268	1.044	1.034
Ya'an	1.179	1.036	1.209	0.998	1.036
Suining	1.104	0.998	1.101	0.984	1.048
Average value	1.144	1.019	1.140	1.049	0.999

MI indicates total factor productivity index; *EC* reflects comprehensive technical efficiency; *TC* reflects technical progress; *PEC* indicates pure technical efficiency; *SEC* reflects scale efficiency. When each value is greater than 1, it indicates that the current level has increased compared with the previous level; when each value is equal to 1, it indicates that the current level is consistent with the previous level; when each value is less than 1, it indicates that the current level has decreased compared with the previous level.

3.3 Decomposition of urban land use eco-efficiency of cities in Chengdu Plain Economic Zone, 2012-2021

Looking at the cities (Table 4), the *MI* of land use eco-efficiency of all cities in the eight cities of the Chengdu Plain Economic Zone from 2012 to 2021 are all greater than 1, indicating that the overall trend of land use eco-efficiency of the cities in the Chengdu Plain Economic Zone is better, and all of them have reached the efficiency frontier. The *MI* of Chengdu City is the lowest, only 1.047. As the capital of Sichuan Province and the centre of economic development in the Chengdu Plain Economic Zone, Chengdu City has great strength and economic support, but it is obviously mismatched only in terms of the *MI*. the average annual growth rate of *TC* reaches 14%, and the Progress Indexes of the eight cities in the Chengdu Plain Economic Zone are all greater than 1, which means that the Chengdu Plain Economic Zone is in a state of technological advancement all the time in the process of development. the average annual growth rate of *PEC* is greater than 1. progress. The average annual growth rate of *PEC* is 4.9%, and Chengdu City, Mianyang City, Ya'an City, and Suining City have *PEC* less than 1 and *SEC* less than 1, showing a declining trend with an average annual decline of 0.01%. The results show that there is still room for improvement in the configuration of factor input-output ratio in Chengdu Plain Economic Zone, and the utilisation of input factors should be increased and technological development and improvement should be continuously promoted.

4 Conclusions and policy recommendations

4.1 Conclusion

This paper uses the SBM-Undesirable model combined with the Malmquist index model to construct an indicator system suitable for measuring urban land use eco-efficiency in the Chengdu Plain Economic Zone, and obtains the following conclusions from the analysis: the average value of urban land use eco-efficiency in the Chengdu Plain Economic Zone fluctuates and decreases most of the time, and there is not a big difference between the year 2021 and the year 2012 in general. The average value of urban land use eco-efficiency of cities in Chengdu Plain Economic Zone is 1.187, and only three cities, Chengdu City, Ziyang City and Leshan City, have a higher than average value of urban land use eco-efficiency.

4.2 Policy recommendations

- (1) Optimise industrial structure and promote the development of eco-industries. Adjust the industrial layout, optimise

the industrial structure, promote the continuous structural adjustment and structural optimisation of industries with overcapacity, reduce and eliminate high energy-consuming and high-polluting industries, support the development of new and high-tech industries, promote the integration of eco-civilisation in the Chengdu Plain Economic Zone, and build a production base that combines eco-ecology, industry, and modern service industries.

(2) Promote technological progress and the rate of technological advancement. Increase efforts to develop applicable technologies that protect the environment while increasing economic production; on the one hand, upgrade the application of environmental protection technologies such as pollution control, energy conservation and emission reduction, and ecological restoration; and on the other hand, promote the improvement of the ecological environment through comprehensive support for the development of new products and services with higher ecological and economic benefits.

(3) Clarify the positioning of the government and give full play to the role of government management. The government should develop low-carbon industries and adhere to green and sustainable development; it should strengthen the formulation and implementation of relevant laws and regulations, and promote the maintenance of the ecological environment by various departments, enterprises and individual citizens; relevant development departments and enterprises should maintain the green environment while intensively utilising the land, and improve the ecological and economic benefits.

(4) Strengthen regional cooperation and enhance economic development. In order to promote the integrated construction of ecological civilisation in the Chengdu Plain Economic Zone, cities in the Chengdu Plain Economic Zone should strengthen regional cooperation, establish appropriate partnerships, reduce the waste of production capacity, reduce the duplication of waste of resources, carry out reasonable planning for the input output ratio of resources, promote the construction of ecological civilisation, and improve the eco-efficiency of urban land use.

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