Article

Research on the Enhancement Effects of Using Ecological Principles in Managing the Lifecycle of Industrial Land

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Abstract: This paper introduces a performance level concept for industrial land use. The performance level concept uses ecological principles to evaluate index systems for industrial land. We used this concept to integrate local economics, land use, development potential, environmental health and ecosystem management with innovation, harmony, floral preservation, and shared land use. The concept helps promote the efficient use of industrial land and the sustainable use of land resources. We used the chemical medicine manufacturing industry in Chongqing Changshou Economic and Technological Development Zone as a case study. We selected eight companies for analysis and calculated an industrial land performance level for each company. We created three industrial land performance levels: growth potential type, positive development type, and inefficient recession type. To determine economic development and land sustainability, we applied administrative, economic, legal and technical measures to evaluate the entire lifecycle of industrial land. This lifecycle included preliminary project audit access, mid-period dynamic supervision and post land exit management. We conclude by proposing measures to mitigate environmental harm occurring from the intensive use of land for industrial use.

Keywords: industrial land; ecological concept; performance; lifecycle

1. Introduction

The industrial revolution was one of the main forces of urbanization in China. Urbanization has greatly increased productivity but has also brought many problems such as environmental degradation and economic inequality to China. Industrial production takes up a large amount of land resources, which causes problems such as relatively low resource utilization efficiencies and environmental degradation [1,2]. There are also problems in the utilization of industrial land, such as irrational land use structure, idle land, deferred use and low utilization efficiency [3]. Land resources are thus wasted, causing additional land to be developed for industrial use. Reallocation of land resources during industrial restructuring is an important means to achieve efficient, intensive and sustainable use of industrial land. However, it is an important theoretical and practical issue to decide which enterprises should be eliminated or reduced, and which should focus on development. Therefore, it is necessary to perform a comprehensive evaluation of the performance of industrial land and to supplement this with a method for determining which inefficient industries should close. This must be done by

creating a scientific basis for the rational allocation, and sustainable utilization and management, of industrial land.

Current research on industrial land performance tends to focus on the evaluation of one aspect of industrial land use performance. Research on ecological performance is the most common [4–7], while research on the economic performance of industrial land being the second [8,9] and the intensive land use performance the third [10,11]. Some research has been done on the factors influencing industrial land performance, such as land prices [12,13], industrial land supply [14], GDP per capita [15] and local economic structure and accessibility [16]. A study by Zhu et al. [11] in Singapore found increases in the spatial productivity of industrial estates led to economic policies promoting the development of new district parks (which facilitated the restructuring of the Singapore manufacturing industry and altered the internal structure of businesses, thereby altering their utilization of space).

Previous studies on the performance of industrial land typically only consider one facet of land use, and the purpose of the performance evaluation is often meant to increase industrial performance. There has been little research on all facets of industrial land use. Additionally, research on how to evaluate inefficient industrial land use still needs to be performed.

However, it is not enough to study only the mechanisms of inefficient industrial land use. The concept of sustainable urbanization suggests that urban spaces need to be planned with an understanding of ecological principles to promote environmentally sensitive urban development. In this context, ecological approaches to landscape design are becoming increasingly important. Green infrastructure, green roads and green wedges are some of the more important concepts developed for this approach. Exploring the lifecycle management of industrial land, which is indispensable for industrial production, is very important. Such exploration may help save land resources, improve the utilization of land and increase the efficiency of industrial output. Many scholars have studied the Eco-Industrial Park and discussed the recycling path of energy and waste from the perspective of the full lifecycle of an industrial area [17–20]. Previous research, however, has neglected the inputs and reuse of such land. Therefore, it is necessary to perform research on the entire life cycle of industrial land.

There has been little research on the management of industrial land. Existing research has focused on pre-planning [21–24] and post-management of industrial land [25,26], conversion of industrial land [27–30], issues related to the transformation of industrial land such as soil pollution [31] and different kinds of service planning [32]. Needham et al. [33] conducted research on the management and decision-making of industrial land from the perspective of the business occupying the land. This research focused on only one point in time instead of the entire lifecycle of the land. Thus, the evaluation of industrial land performance considered only one aspect rather than an entire comprehensive theory. This study describes the importance of ecological approaches in landscape design studies. Urban design is associated with urban planning and landscape architecture, which are disciplines for organizing space. These disciplines approach urban design in different ways. Landscape architects approach urban design as designing the urban landscape. Conversely, landscape architects approach urban design as a large-scale architectural practice. Urban designers and urban planners view the details of city planning as a process in which analysis and aesthetic issues are identified. Urban design is therefore a field that provides interdisciplinary interaction and manages the process of urban design as a means of resolving problems in metropolises and residential areas. Problems are thus approached holistically in urban design. Urban design is not only aesthetically pleasing but also achieves sustainable, high quality, practical designs. This is done by considering ecological, sociological and economic factors. Landscape architects, conversely, design recreational areas, cultural areas, urban open spaces, pedestrian zones, highways, industrial and agricultural areas, and urban and rural areas. These areas are all necessary for a city to be sustainable.

Based on previous research, this article begins with a comprehensive performance evaluation of industrial land. The evaluation uses a multi-dimensional aggregation model and evaluation index system for industrial land performance to examine inefficient industrial mechanisms. The evaluation

allows us to explore lifecycle management mechanism for industrial land, from early approval to mid-term dynamic monitoring, and the termination of land for industrial use. We also examine ways to realize efficient and intensive utilization of industrial land, guide the sustainable and healthy development of land in industrial parks, expand research on efficient and sustainable use of land resources and provide better decision-making for urban land planning and utilization management. We created our multi-dimensional aggregation model and evaluation index system using ecological principles.

2. Research Design

The performance of industrial land is determined by the rational use of industrial land, the efficiency of land use, the ecological security of land use and the evolution of a particular industry. The performance evaluation of industrial land is based on ecological principles and an evaluation index system that reflects the utilization status and future trend of the industrial land. The performance evaluation includes innovative economic performance, land performance, enterprise development potential performance, eco-environmental performance and ecological management performance.

2.1. Economic Performance

The measurement of economic performance includes the economic value of industrial land, the economic interest relationship between industrial land and stakeholders and sustainable economic development of industrial land. It also analyzes reasons for the inefficient use of industrial land, including factors constraining development, regional comparative advantages and low margin profits or loss because of high production costs. Therefore, we focus on the economic impact and benefits of industrial land. The economic benefits of land use are the pursuit of maximum economic benefits and efficiency. This can be measured by the input and output of industrial land, total revenues and taxes and yield ratios.

2.2. Intensive Land Use Performance

Improving the intensive use of land, promoting industrial agglomeration and promoting a centralized layout are the necessary requirements to transform and upgrade industrial economies. Currently, there are industrialization problems such as low development intensity, low efficiency, non-intensive land utilization and less available land than needed for industrial use. Therefore, intensive land use has become an important means of increasing the performance of industrial land. Intensive land use indicators are the index of intensity and the efficiency of land use. Land use intensity is the plot ratio and building factor. The efficiency of land use is the allocation of land for different purposes in both quantity and space.

2.3. Enterprise Development and Potential Performance

The corporate lifecycle theory and marginal utility theory suggest that operational efficiency and the potential development of new enterprises fluctuates with the business growth cycle. As businesses develop, they should consider factors such as the environment, society and ecosystems. Innovation and development by enterprises is determined in part by the land the enterprise occupies [17]. Therefore, the sustainable development of enterprises is an important factor in the performance evaluation of industrial land. Enterprise performance and developmental potential is determined by industrial input ability, technology equipment levels and research and development innovation potential.

2.4. Eco-Environmental Performance

The ecological performance dimension reflects the impact and contribution of the industrial land to the ecosystem. Industrial land may help protect the environment by conserving ecological resources. Currently, as environmental pollution and ecological degradation impact human life,

industrial production should reduce resource utilization and maximize the added value of resource consumption. Production should also minimize waste, but, if waste is produced, it should be disposed of safely to minimize land pollution and maintain ecological health. Moreover, industrial land should maintain its structure to maintain its stability and sustainability. Evaluation indexes are measured by added industrial unit value, raw material, water consumption, greenhouse gas emissions, waste utilization rate and ratio of green space.

2.5. Ecological Management Performance

The ecological management performance is the ability of enterprises to fulfill their social responsibilities in a given period. It also reflects the ability of enterprises to achieve the goal of "minimum impact and maximum output" of industrial land. Assessments of ecological management level may suggest how enterprises can change to low input and low consumption, or low pollution and high efficiency, to eliminate destruction of ecologically valuable land. The assessment is based on credit rating, including environmental management system certification, ecological efficiency recognition, clean production audit pass rate and environmental protection behavior.

We created our multidimensional aggregation model of industrial land use performance according to characteristics and functions of industrial land (Figure 1). With the help of radar analyses to visualize our theoretical model, we classified performance according to the distance to the radar center. The solid line in the middle of Figure 1 represents the average performance of industrial land of a particular type, while the dotted line represents the performance value of industrial land. Performance is lower near the center and higher near the edge.
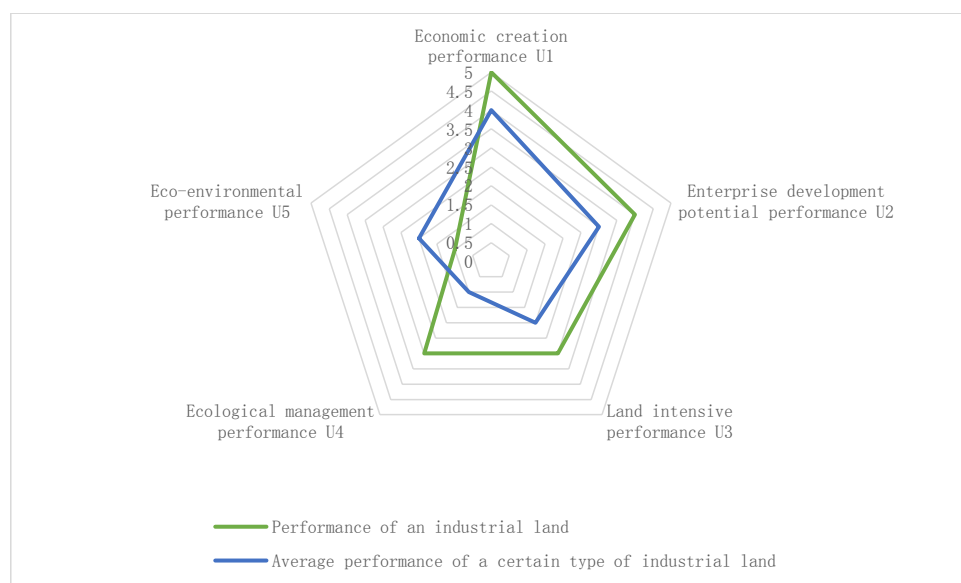

Figure 1. Multi-dimensional aggregation model of industrial land performance based on ecological principles.

2.6. Evaluation Index System

The performance evaluation indexes were selected to establish the performance evaluation system for industrial land performance. This was based on ecological principles according to the scientific, systematic, hierarchical and operational principles. These principles were developed from three aspects. First is the target level, which reflects the overall performance of industrial land from a macro perspective. Second is the standard level, which decomposes the evaluation target, and which considers economic creation performance, intensive land use performance, enterprise development potential performance, eco-environmental performance and ecological management performance.

Third is the index level, which evaluates the angle of quantification, and determines the weight of each index according to entropy methods and expert comprehensive scoring (see Table 1); the calculation process is as follows:

(1)　Define the entropy of the index j using Equation (1) (named e_j):

$$e_j = -k \sum_{i=1}^{m} p_{ij} \ln\left(p_{ij}\right) \tag{1}$$

where k represents the adjustment coefficient, k = 1/lnm, and k > 0. p_{ij} represents the normalized value of the evaluation index j of the participant i.

(2)　Calculate the effect value g_j of the indexj:

$$g_j = 1 - e_j \tag{2}$$

(3)　Calculate the entropy weight of index j (named w_j):

$$w_j = \frac{g_j}{\sum_{j=1}^{n} g_j} \tag{3}$$

The larger the entropy is, the less the weight of the index.

Table 1. Evaluation index system and the weighted value of industrial land performance based on ecological principles.

Target Level	Rule Level	Indicators Level	Unit	Data Source	Weight
Industrial land performance	Economic creation performance U1(0.27)	Fixed assets investment in industrial land B_1	RMB ten thousand	Statistical information	0.17
		Output degree of industrial land B_2	RMB ten thousand	Statistical information	0.23
		Gross income of unit land B_3	RMB ten thousand/km^2	Statistical information	0.11
		Unit land tax B_4	RMB ten thousand/km^2	Statistical information	0.28
		Yield ratio B_5	%	Statistical information	0.21
	Enterprise development potential performance U2(0.13)	Industry input ability B_6	-	Statistical information	0.30
		Average profit margin B_7	RMB ten thousand/km^2	Statistical information	0.22
		Technical equipment level per capita B_8	-	Enterprise questionnaire	0.20
		R & D expenditure growth rate B_9	%	Enterprise questionnaire	0.14
		Rate of putting into use for research results B_{10}	%	Enterprise questionnaire	0.14

Table 1. *Cont.*

Target Level	Rule Level	Indicators Level	Unit	Data Source	Weight
Industrial land performance	Land intensive performance U3(0.22)	Comprehensive floor area ratio of industrial land B_{11}	%	Land survey data	0.26
		Building factor of industrial land B_{12}	%	Land survey data	0.21
		Idle rate of industrial land B_{13}	%	Land survey data	0.18
		Personnel density of unit land use B_{14}	person/km^2	Land survey data	0.15
		Land use ratio B_{15}	%	Land survey data	0.11
		Other land use ratio B_{16}	%	Land survey data	0.09
	Eco-environmental performance U5(0.24)	Unit industrial added value raw material consumption B_{17}	t/RMB ten thousand	Enterprise management department	0.22
		Unit industrial added value water consumption B_{18}	t/RMB ten thousand	Enterprise management department	0.22
		Comprehensive treatment rate of unit value added waste B_{19}	%	Enterprise management department	0.22
		Unit added value for greenhouse gas emissions	t/RMB ten thousand	Enterprise management department	0.22
		Greenbelt rate B_{21}	%	Land survey data	0.12
	Ecological management performance U4(0.14)	Pass environmental management system certification B_{22}	-	EPA information	0.28
		Enterprise ecological efficiency recognition B_{23}	-	Enterprise questionnaire	0.25
		Qualified rate of cleaner production audit B_{24}	-	EPA information	0.24
		Enterprise environmental protection behavior credit rating B_{25}	-	EPA information	0.23

3. Performance Evaluation of Industrial Land in Research Area

3.1. Overview of Research Area

Business enterprises are the primary sources of intensive industrial land use. The analysis of the performance and potential of industrial land from the point of view of the business makes our analysis more targeted and of greater practical significance.

With a planning area of 80 square kilometers and a developed area of 35 square kilometers, the Changshou Economic Development Zone was approved by the State Council of the People's Republic of China in 2010. The zone was named the National Economic and Technological Development Zone and was later renamed the Chongqing (Changshou) Chemical Industry Park. The zone includes development of new energy and new materials, iron and steel metallurgy, equipment manufacturing, electronic information industry at the National Circular Economy Pilot Park, National New Industrialization Demonstration Base, National Intellectual Property Pilot Park, National Demonstration Base for New Chemical Materials and High & New Technology Industrialization,

National Industrial Waste Comprehensive Utilization Project Demonstration Base and Chinese Steel Industry Demonstration Base.

Currently, China's chemical industry is facing multiple pressures owing to limited resources, environmental degradation and limited markets. Changshou Economic Development Zone attempts to actively adapt to these pressures. The zone was placed around the Chongqing Industrial Highland and National Comprehensive Chemical Industrial Park to highlight innovation driven development, transformation and upgrading development, balanced development, adherence to product projects, utilities, environmental protection, logistics, and management services. This has been named the construction concept of "five-integrations." To construct the Modern Industrial Park, there was a balance between the environment, production and development, as well as promoting the transformation and upgrading of chemical industry, the adjustment of product structure, promotion of technological innovation and development of the circular economy (a model of economic development characterized by "3R": resource reducing, recycling and reuse). The zone holds 46 enterprises in total, which had industrial outputs of over 25 billion renminbi in 2016.

The land for the chemical medicine manufacturing industry in Chongqing Changshou Economic and Technological Development Zone is characterized by the chemical industry. This industry was our primary research object. We conducted a quantitative analysis of the industry based on the concept of ecological industrial performance. This provided us with a reference point for examining other industrial parks and industrial land uses.

3.2. Research Methods

3.2.1. Data Sources and Analysis

In this study, the land used for chemical medicine manufacturing in Chongqing Changshou Economic and Technological Development Zone was our primary research area. From April 2016 to September 2016, we selected eight chemical technology manufacturers in the development zone to answer a questionnaire survey. We investigated their basic conditions, inputs and outputs, and construction sites. We verified our data using the Land Bureau, Statistics Bureau and Environmental Protection Bureau. To protect the privacy of these eight businesses, we used the identifiers C1 to C8.

We analyzed data using the range normalization method. The dimensional difference of our data was excluded.

$$Y_{ij} = (1 - a) + a \times \left(X_{ij} - X_{i\,min} \right) / \left(X_{i\,max} - X_{i\,min} \right) \tag{4}$$

$$Y_{ij} = (1 - a) + a \times \left(X_{i\,max} - X_{ij} \right) / \left(X_{i\,max} - X_{i\,min} \right) \tag{5}$$

where Y_{ii} represents the standardized value, X_{ij} is the jst element indexed to the original value for i, and X_{imax} and X_{imin} are the maximum value and minimum value of the corresponding index and a is equal to 0.9. In this index system, Equation (4) is applicable for the positive index, and Equation (5) for the negative index.

3.2.2. Industrial Land Performance Index by Numerical Model

We created a numerical model for use in our evaluation index system of industrial land performance. The model incorporated the ecological principles listed above to calculate a comprehensive evaluation index Pi on low efficiency industrial land. The model is:

$$P_i = \sum_{i=1}^{n} Y_{ii} \times W_i \tag{6}$$

where P_i represents the Industrial land performance comprehensive index of i (the object being evaluated); Y_{ii} represents the standardized value; W_i represents the weight of Y_{ii}; and n represents the total number of indexes.

3.3. Analysis of Results

3.3.1. Comprehensive Evaluation Result

The analysis of results shows that of the eight industrial areas used for chemical technology manufacturing in the Economic Development Zone, only 25% were above the average industry performance. This indicates that the sustainable development level of the majority of industrial lands is medium. Therefore, there are many areas where development performance may be improved. The highest performance value was C1 industrial land at 7.06503. This was primarily because of the high enterprise development potential and the high ecological environment performance. The second highest was C5 industrial land at 4.74189. The lowest was C2 industrial land, with only 3.61158. This was mainly because it had the lowest ecological environment performance and management of all industrial lands surveyed (see Table 2).

Table 2. Index of performance evaluation for eight industrial lands for chemical technology manufacturing in the Economic Development Zone.

Name	U1	U2	U3	U4	U5	Performance Value of Industrial Land
C1 (JT Co)	4.75231	14.98415	1.63174	11.25158	5.53289	7.06503
C2 (ZGCo)	4.88214	4.75683	1.76186	2.57942	4.77387	3.61158
C3 (KLCo)	5.19485	2.31537	1.71865	4.53077	6.22867	4.04111
C4 (FACo)	5.36411	2.59403	1.81070	2.97785	6.59979	3.82254
C5 (YTHCo)	4.35711	9.46247	1.65619	5.21113	5.14514	4.74189
C6 (YCCo)	5.83639	4.04254	1.77218	3.52387	6.19689	4.20453
C7 (BTCo)	4.75914	4.25521	1.73478	2.88137	5.17712	3.63612
C8 (XFCo)	5.42173	3.79343	1.78976	3.52553	4.99523	3.89622
Average industrial value	5.07097	5.77550	1.73448	4.56019	5.58120	4.37738

3.3.2. Resistance Factor of Industrial Land Performance Level

To study characteristics of the frequency distribution of industrial land performance, and to analyze the resistance factors that can affect those performance levels, we conducted a general analysis of the statistical characteristics of the industrial land sub-systems (see Figure 2 and Table 3). We found that: (1) The frequency distribution of ecological and enterprise development potential performance was significantly skewed, as well as having poor symmetry. This suggests that ecological benefit is largely different from enterprise sustainable development. The enterprise development potential performance interval value is higher than others, indicating that the development potential of industrial land enterprises is higher than other subsystems. (2) In addition to economic creation performance, the median value of the other four sub-performances is less than the mean, and the deviation coefficient is greater than 0. This suggests that the data distribution has low value aggregation, and high values in discrete status. (3) The kurtosis coefficient of ecological performance is slightly higher than that of other subsystems, indicating that subsystem variability is small.
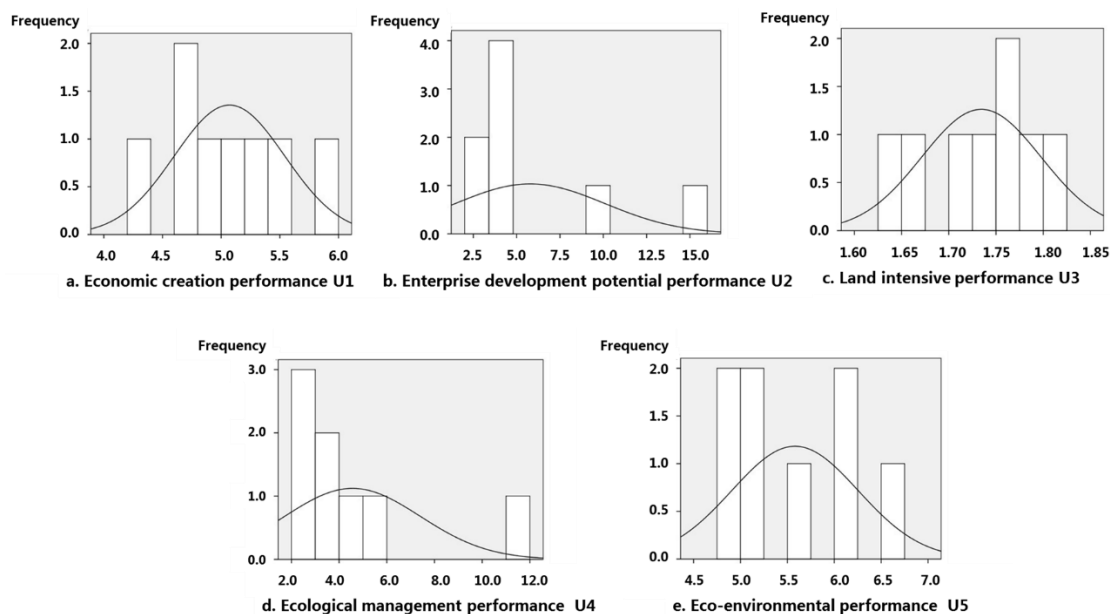
Figure 2. (**a**–**e**) Frequency distribution chart for the manufacture of chemical agents in the Economic Development Zone.

Table 3. Comparison of frequency distributions for sub-performance scores of industrial lands for chemical technology manufacturing in the Economic Development Zone.

	Economic Creation Performance (U1)	Enterprise Development Potential Performance (U2)	Land Intensive Performance (U3)	Eco-Environmental Performance (U4)	Ecological Management Performance (U5)
Mean value	5.0710	5.7755	1.7345	4.5602	5.5812
Median	5.0385	4.1489	1.7483	3.5247	5.3550
Deviation factor	0.1560	1.7450	−0.6660	2.3300	0.4250
Kurtosis coefficient	−0.4020	2.6180	−0.7190	5.7860	−1.5890
Interval value	1.4793	12.6688	0.1790	8.6722	1.8259

In sum, resistance factors in the performance evaluation of industrial lands for chemical technology manufacturing in the Economic Development Zone mainly include enterprise development potential performance and eco-environmental performance. While the industrial lands were located in the chemical concentration area of Chongqing, the chemical technology for manufacturing in the Changshou Economic Development Zone is a large-scale industry with numerous products. The industrial structure is currently unsustainable because of ecological degradation, a low proportion of high value-added products, high energy consumption, lack of development potential, and weak competitiveness compared with other advanced regions.

3.3.3. Performance Level Types for Industrial Lands

To judge the types of industrial land scientifically, we created four classification schemes according to the index of land value for particular enterprises. (1) Intensive and efficient type: five indexes of industrial land are higher than the average performance value, which is the ideal development model of the industry with good economic development, high intensive land utilization, good ecological management and environment coordinated development, and good ecological health. (2) Growth potential type: Among the five indicators, one or two indexes are lower than the average performance value of industrial land. This indicates that the land use maintains a sustainable development level with high industrial input-output efficiency, good potential for development, but too much short-term focus on the economic interests of enterprises, as well as neglecting to further upgrade industrial

technology. Therefore, there is still room for improvement in technology and personnel training. (3) Positive development type: There are three indexes below the average performance value. The land use has reached sustainable development, but the industrial land supporting measures and ecological management mechanisms are imperfect with low utilization efficiency of the industrial land, as well as poor industrial land structure rationally. Therefore, there is an urgent need to improve the industrial service support system. (4) Low efficiency recession type: There are more than four indexes below the average performance value. The land use does not meet the requirements of sustainable development, and the enterprises for these lands have poor development potential and ecological management owing to poor input and output efficiency. The land is inefficient industrial land, which should begin an exit mechanism.

We found that eight enterprises in the Economic Development Zone were not efficient and intensive enterprises. Consequently, there was room to improve industry performance. The eight chemical medicine manufacturing industrial lands can be divided into three categories (see Table 4). C1, C4 and C6 fall into the growth potential type category as for each of them two indexes were below the average control value of industrial land performance. C3, C5 and C8 were in the positive development type category as for each of them three indexes were below the average control value of industrial land performance. C2 and C7 were in the low efficiency recession type category as C2 had four indexes below the average control value of industrial land performance, while C7 had all indexes below the average control value.

4. Whole Lifecycle Management Mechanism for Industrial Land

Lagging economic interest and exit supervision mechanisms result in the end of the lifecycle for most enterprises that are reluctant to withdraw from the land. Few industrial land withdrawals are currently being done, which means that low-speed and low-quality withdrawal has seriously hampered intensive land use and industrial upgrading. This paper suggests several lifecycle management ideas and proposes a whole lifecycle management mechanism for industrial land. Therefore, we adopt the contract platform for land transfers to implement dynamic evaluation and management for the whole process. This allows for perfect preliminary audit access, interim dynamic regulation and late land withdrawal management from administrative dimensions, economic dimension, legal dimension and technical dimension. The result is a balance of interests between all parties that are helping to continuously improve the level of sustainable land use (see Figure 3).
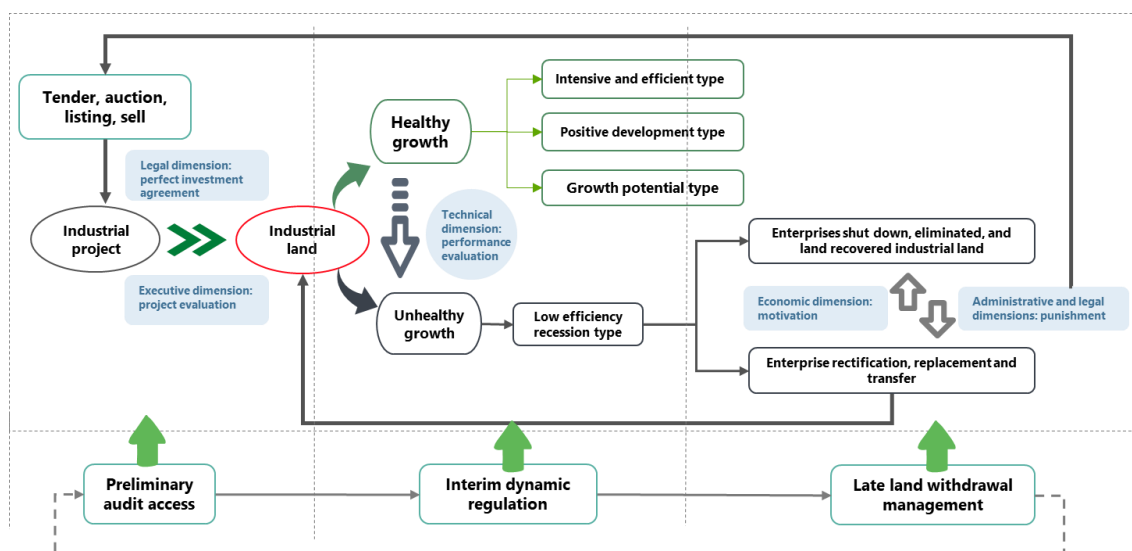

Figure 3. Schematic diagram of the whole lifecycle management mechanism for industrial land.

A pre-audit of industrial projects prevents land from becoming idle or used inefficiently. To improve the access threshold, which improves the investment agreement, we propose strengthening joint trial evaluation projects, avoiding risk arising from the introduction of the project and restraining and standardizing the investment behavior of enterprises for liability in breach of contract. For interim dynamic regulation, the project construction supervising organization should conduct a comprehensive dynamic supervision on the full construction process. This establishes the industrial land evaluation mechanism and the project accountability mechanism. By regularly conducting industrial land performance evaluations, the evaluation results may be used as the basis for performance management of Industrial Park upgrades, with withdrawal of inefficient industrial land. The evaluations may also strengthen dynamic inspections and timely disclosures of industrial project land, as well as the implementation of project responsibility mechanisms. For late land withdrawal management, such evaluations may control and integrate the existing inefficient industrial lands, while also establishing incentive mechanisms and combining withdrawal mechanisms with fairness and efficiency. This paper suggests corresponding management measures for different types of industrial lands to revitalize the stock of land and promote the optimal allocation of land resources, intensive land use and economic utilization, and sustainable ecological development (see Table 4).

Table 4. Performance type and exit mechanism for industrial lands performing chemical technology manufacturing in the Economic Development Zone.

Name	Number of Indexes Below the Average Control Value	Performance Type	Corresponding Management Measures
C1 (JT Co)	2	Growth potential type	Transformation and Upgrading. It shall deeply explore the sustainable development potential land, strengthens policy guidance and support, realize the transformation of enterprises to the low-carbon and green economic development.
C6 (YCCo)	2		
C4 (FACo)	2		
C3 (KLCo)	3	Positive development type	Improves and Transformation. In view of the weak link of industrial land development, it should strengthen control, coordinate and guide for the industrial land's space resources, it improves the performance level of this type of industrial land.
C5 (YTHCo)	3		
C8 (XFCo)	3		
C2 (ZGCo)	4	Low efficiency recession type	Closed down. Enterprises for these lands should be closed down, and industrial lands involved should be recovered or dealt by other similar measures.
C7 (BTCo)	5		

There are different management measures for different types of industrial land. First, the growth potential type should strengthen collaborative development and integration between enterprises, promote enterprises to rationally expand, enhance the level of industrial technology upgrading, enhance land use performance level and drive sustainable development of industrial lands of the same type while strengthening the dynamic monitoring of land use of this type. This should be based on the maintenance of the reasonable and orderly development of existing industrial land.

Second, the positive development type should strengthen the dynamic regulation of industrial land within a prescribed time limit, encourage enterprises to improve industrial land supporting measures, optimize the industrial land structure, accelerate the transformation to low-carbon green energy use, integrate energy savings with emission reduction into product development and enterprise culture, enhance the comprehensive strength of the enterprise and promote the added value of the products by reducing the destruction of ecological goods to realize a stable development track. If there is no rectification within the prescribed time limit, industrial land should be replaced or transferred.

Third, the low efficiency recession type should be closed down, the exit mechanism of inefficient industrial land should be established and perfected to promote rational voluntary relocation and revitalized land should be enhanced with the optimal allocation of land resources to achieve intensive land use and sustainable ecological development.

5. Discussion and Conclusions

Industrial land is the main source of city land use. Sustainable utilization of such land can therefore improve the use of land resources. To construct the industrial land comprehensive performance evaluation index system, we explored inefficient industrial land evaluation methods, and studied the management strategies of inefficient industrial land use caused by urbanization and industrialization processes. We also studied land resources, ecological processes and social pressures, which are very important in improving the sustainable land use.

Using previous studies, this paper attempted to integrate ecological principles into the evaluation model of industrial land performance from an ecological perspective. We quantified the economic and ecological efficiency of land use to combine both, forming a new method for the comprehensive evaluation of industrial land use. Performance was determined by examining the performance of the economy, industrial land, eco-environmental management and ecological management. This method provides insight into intensive land use evaluation and research. Compared with traditional performance evaluations of land use, the industrial land performance evaluation system proposed in this paper reflects the effects of industrial land use comprehensively and provides references for the regional screening of industrial land. Additionally, the analysis of the health level of industrial land ecosystems has great significance for optimizing the urban land ecosystem. Other cities also can adopt this evaluation index system to evaluate the land use efficiency of enterprises, screen inefficient land enterprises, and apply differential exit criteria for different projects in combined industries. This may be done for energy project consumption, safety production and environmental protection.

After evaluating the Chongqing Changshou Economic and Technological Development Zone, we found that sustainable development of eight chemical medicine manufacturing industrial lands was mainly in the middle to general level. There is still much room for improvement with the enterprises. We found that the land use performance of three enterprises were better than average, three enterprises were average, and two were below average. This was determined by dividing the enterprises into three types: the growing potential type, the positive development type, and the inefficient declining type. By analyzing the statistical characteristics of subsystem values for industrial land performance, we found that the development potential and ecological management of the enterprises were the main obstacle for the industrial land performance level of chemical industries. Therefore, we should conclude that enterprises should strengthen the coordination, planning and guidance of the spatial resources of their industrial land. This should overcome any weak links in the development of the industry, and continuously improve the management level of industrial land. Enterprises can thereby realize the rational allocation of industrial land structure and provide favorable conditions for the sustainable development of industrial land. At the same time, we encourage enterprises to adopt energy conservation, emission reductions in product development and corporate culture, while also developing the green economy, promoting low-carbon transformation and upgrading enterprises. This should enhance the overall performance level of industrial land use.

This study found that there was insufficient motivation for relocation, conversion, closure or upgrading of industrial land that currently has poor efficiency. Regulations governing the exit of industrial land with poor efficiency are imperfect, funds are strained, the incentive policy is insufficient and the exit supervision is lacking. Therefore, we suggest the establishment and improvement of exit mechanisms for industrial land with poor efficiency, promoting the revitalization of idle land and optimizing the allocation of land resources. This should become a priority task for local governments to promote intensive use of industrial land. This should be done by using the administrative, economic, legal and technical means to build the lifecycle management mechanism of industrial land. This must also include project pre-audit access in early stages, dynamic supervision in medium stages and land exit management in late stages. This will help promote the intensive use of industrial land.

The performance evaluation index system of industrial land based on ecological principles in this paper balances social, economic and ecological benefits. However, owing to the complex and variable factors influencing industrial land use, the selection of ecological indicators and economic

indicators is often different for different industries. Currently used index system are not mature enough for widespread use. In this paper, we studied only industry land use performance evaluation for the chemical drugs manufacturing industry. Setting up assessment and evaluation mechanisms for industrial land use for other industries, and combining them with the different variables of other industries, will need to be undertaken in future research.

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