Research on comprehensive evaluation of Payment for ecological services effect of environmental pollution loss in Industrial Park

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Research

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ABSTRACT

Background: China's industrial parks are the main force of economic development，payment for ecological services（PES）effect of environmental pollution loss in industrial parks is significant for sustainable development of industrial parks. In order to explore effective method of Payment for ecological services effect evaluation（ECEE）of the environmental pollution loss（EPL）in industrial parks, based on literature review and current situation analysis, 24 evaluation indicators of four kinds were selected to build the evaluation indicator system.

Methods: According to requirements of Payment for ecological services effect evaluation of environmental pollution loss in industrial parks, niche suitability model (NFM) is introduced, based on analysis and improvement of which, spatial niche suitability model (SNSM) is constructed. Then, the application test of SNSM is carried out using related research data, taking Nanjing MV Industrial Park as an example.

Results: The evaluation results show that the Payment for ecological services effect of environmental pollution loss in Nanjing MV industrial park shows an upward trend from 2011 to 2018, but the upward situation is imbalanced, and effect improvement of ecological environment compensation inputs and ecological environmental pollution is obviously lagging behind, and still the future work focus of Nanjing MV Industrial Park.

Conclusions: Through comparative analysis, it is shown that the evaluation results of spatial niche suitability model are more in line with the actual situation of Nanjing MV Industrial Park, and this method is more suitable for the comprehensive evaluation of Payment for ecological services effect of environmental pollution loss. The research results of this paper provide an effective quantitative analysis method for Payment for ecological services effect management and prevention of Payment for ecological services risks of industrial parks.

KEYWORD：Payment for ecological services effect; comprehensive evaluation; space niche suitability model; environmental pollution loss; industrial park

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1. Background

The development of China's industrial parks not only promotes the rapid economic growth, but also produces environmental pollution to a certain extent. Evaluation of Payment for ecological services effect of environmental pollution loss has been put forward, and gradually becomes a major problem to be solved (Han XY, 2019). Ecological compensation first came into being in western developed countries. Westman WE (1977) first proposed the concept of "natural service" and advocated that environmental polluters should make economic compensation for ecological environment damage. Coughenoor MB, et al. (1985) studied the ecological system damage caused by energy exploitation and utilization in nomadic pastoral areas in the west of the United States, as well as the ideas and specific ways to restore the ecological system Methods: Arrow K, et al. (1993) studied the case of environmental pollution and its pollution loss of the U.S. ocean and atmosphere by the emergency valuation team of the National Oceanic and Atmospheric Administration of the United States, constructed the assessment model, and reached valuable conclusions. Since then, the research on the charging effect of ecological service system has been comprehensively developed, and the ecological compensation system has gradually become a development trend in the future (Müller F, 1997).

According to the latest research results, overseas evaluation of ecological compensation effect is developing towards the direction of multiple standards and technologies (López BM, et al., 2019). The evaluation of ecological compensation effect involves more and more contents, including: road environmental pollution payment (Cuperus R et al, 1996), ecological compensation of damaged watershed (Loomis J, et al., 2000) Rural ecological compensation (Geussens KG et al., 2019), land pollution ecological compensation (Loft L et al., 2019), etc. In the specific evaluation process, Scholars are considered that the ecological compensation effect of environmental pollution loss should be evaluated in combination with social benefits (Grima N et al., 2018), and the cost- effectiveness of ecological compensation mode (Liu JY et al., 2019) as well as environmental protection and poverty reduction objectives should be fully considered (Ola O et al., 2019). It can be seen that the evaluation of ecological compensation effect in foreign countries has been relatively mature, and a systematic theory and method system has been formed.

The domestic research on this subject began in the early 21st century, more than 30 years later than that of developed countries. Most of the studies are based on the research results and experience of foreign countries to explore the evaluation method of Payment for ecological services effect of environmental pollution loss suitable for China's national conditions (Xu DW and Li B, 2015). In China, Deng JR et al. (2001) first proposed that ecological compensation should be integrated into China's environmental impact assessment; Wang HM and Xu HH (2008) studied how to introduce ecological compensation into environmental impact, and explored its application in combination with the actual situation. Since 2010, more and more research results have been made on Payment for ecological services effect and the system of ecological compensation in China, mainly focusing on agriculture, grassland, water area, forest, electricity, etc. The theoretical research on regional ecological compensation started in 2001 (Du WP 2001), and the research on Industrial Park ecological compensation started in 2013 (Wang X et al., 2013). Relevant research results are as follows: KL et al. (2018) analyzed the performance of ecological compensation in the ecological barrier area, studied the evaluation method and application of ecological performance; Jin LH et al. (2019) incorporated GEP into the performance evaluation and evaluation system of ecological compensation, and studied the effective method of implementing the performance of ecological compensation to promote the growth of GDP; Zeng XG et al. (2019) used Xilin Gol Grassland taking the original ecological compensation as an example, this paper studies the impact of ecological compensation performance on performance, and explores effective ways to improve the performance of ecological compensation. There are also many domestic researches focusing on environmental pollution and ecological compensation in urbanization construction (Han XY et al., 2018).

From the above literature review, it can be seen that the research on the evaluation of Payment for ecological services effect has been relatively mature, but due to the differences in social system, ecological compensation concept and compensation theme, the results cannot be directly applied in China. In China, there are relatively few research results on ecological compensation and evaluation of Payment for ecological services effect. Most of the researches on this issue are not in-depth, and the existing research results cannot meet the needs of practice. Theoretical results and practical guidance are urgently needed in research content, compensation method, compensation model and its application. Therefore, it is very crucial and urgent to study the evaluation of Payment for ecological services effect of environmental pollution loss in industrial parks.

2. Materials and Methods

2.1 Selection of evaluation indicators and definition of evaluation standard

In order to realize the comprehensive evaluation of the Payment for ecological services effect of environmental pollution loss in industrial parks, it is necessary to select the multiple comprehensive evaluation indicators to build the evaluation indicator system of Payment for ecological services effect of environmental pollution loss in industrial parks (Bundy A et al., 2019). On the basis of comprehensive analysis, drawing on the latest research results in China and abroad, and fully considering the actual situation of ecological compensation for environmental pollution loss in China's industrial parks, four categories are selected:

coordinated economic development, ecological compensation inputs, ecological environmental pollution and ecological environmental pollution treatment, with a total of 24 comprehensive evaluation indicators. These evaluation indicators comprehensively reflect the Payment for ecological services effect of environmental pollution loss in industrial parks. According to the selected specific evaluation indicators, it is built the comprehensive evaluation indicator system of Payment for ecological services effect of environmental pollution loss in industrial parks, seen in Table 1.

Table1.Comprehensive evaluation indicator system of ECE of EPL in Industrial Park

target layer	Criterion layer	Indicator layer	unit	Indicator properties
Comprehensive evaluation of Payment for ecological services effect of environmental pollution loss in Industrial Parks	Indicators of coordinated economic development（X_1）	Per capita gross output value（X_{11}）	10000yuan /p	forward pointer
		Return on equity（X_{12}）	%	forward pointer
		Growth rate of total industrial output（X_{13}）	%	forward pointer
		Energy consumption intensity（X14）	ton/10000yuan	contrary indicator
		EC CO_2 emission intensity（X15）	ton/10000yuan	contrary indicator
	Indicators of ecological compensation inputs（X_2）	Compensation rate of EPL（X_{21}）	%	forward pointer
		Environmental greening rate（X_{22}）	%	forward pointer
		Ecological landscape index（X_{23}）	index	forward pointer
		IEPT / total output value（X_{24}）	%	forward pointer
	Indicators of ecological environmental pollution（X_3）	Sulfur dioxide emission concentration（X_{31}）	mg/m^3	contrary indicator
		NOx emission concentration（X_{32}）	mg/m^3	contrary indicator
		Total suspended particle concentration（X_{33}）	mg/m^3	contrary indicator
		IWW emission intensity（X_{34}）	$10000ton/km^2$	contrary indicator
		Emission intensity of solid waste（X_{35}）	ton/km^2	contrary indicator
		Air pollution index（X_{36}）	%	contrary indicator
		Water pollution index（X_{37}）	index	contrary indicator
		Land pollution index（X_{38}）	index	contrary indicator
	Indicators of environmental pollution treatment（X_4）	Standard rate of IW treatment（X_{41}）	%	forward pointer
		Standard rate of IWG emission treatment（X_{42}）	%	forward pointer
		Comprehensive utilization rate of ISW（X_{43}）	%	forward pointer
		Investment intensity of EPT rate（X_{44}）	$10000yuan/m^2$	forward pointer
		Domestic waste treatment rate（X_{45}）	%	forward pointer
		Domestic wastewater treatment rate（X_{46}）	%	forward pointer
		Comprehensive index of EPT（X_{47}）	%	forward pointer

ECE: Environmental pollution loss; EPL：Environmental pollution loss; IEPT：Investment in environmental pollution treatment；IWW：Industrial waste water；IWW: Industrial waste gas；ISW：Industrial solid waste；EPT: Environmental pollution treatment.

The Chinese government has formulated relevant laws and regulations on environmental pollution, environmental pollution treatment, treatment effect and ecological compensation in industrial production, as well as the actual situation of industrial parks. It has comprehensively, scientifically and effectively defined the specific evaluation indicators selected and the evaluation standards for Payment for ecological services effect of environmental pollution loss in industrial parks. There are two levels of evaluation criteria for the Payment for ecological services effect of environmental pollution loss in industrial parks, namely, the evaluation indicator level and the result level (Greco S et al., 2019). Definition of evaluation standard is based on the specific laws and regulations issued by the Chinese government, with the latest research results in China and abroad used for reference. See Table 2 for the evaluation criteria of specific evaluation indicators.

Table2. Evaluation standard of Payment for ecological services effect of evaluation indicators

No.	Indicators name	LevelI	LevelⅡ	LevelⅢ	LevelⅣ	LevelⅤ
1	Per capita gross output value（X_{11}）	>15	10-15	8-10	5-8	<5
2	Return on equity（X_{12}）	>30	20-30	10-20	5-10	<5
3	Growth rate of total industrial output（X_{13}）	>10	8-10	5-8	2-5	<2
4	Energy consumption intensity（X14）	0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	>2
5	EC CO_2 emission intensity（X15）	0-1	1-1.5	1.5-2.0	2-2.5	>2.5
6	Compensation rate of EPL（X_{21}）	>95	80-95	70-80	60-70	<60
7	Environmental greening rate（X_{22}）	>30	20-30	10-20	5-10	<5
8	Ecological landscape index（X_{23}）	>0.8	0.7-0.8	0.6-0.7	0.5-0.6	<0.5
9	IEPT / total output value（X_{24}）	>2	1.5-2	1-1.5	0.5-1	<0.5
10	Sulfur dioxide emission concentration（X_{31}）	0-0.1	0.1-0.15	0.15-0.2-	0.2-0.25	>0.25
11	NOx emission concentration（X_{32}）	0-0.05	0.05-0.1	0.1-0.15	0.15-0.2	>0.2
12	Total suspended particle concentration（X_{33}）	0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	>0.4
13	IWW emission intensity（X_{34}）	0-0.5	0.5-1	1-1.5	1.5-2	>2
14	Emission intensity of solid waste（X_{35}）	0-50	50-200	200-350	350-500	>500
15	Air pollution index（X_{36}）	0-50	50-100	100-200	200-300	>300
16	Water pollution index（X_{37}）	0-50	50-100	100-200	200-300	>300
17	Land pollution index（X_{38}）	0-50	50-100	100-200	200-300	>300
18	Standard rate of IW treatment（X_{41}）	85-100	75-85	60-75	40-60	<40
19	Standard rate of IWG emission treatment（X_{42}）	85-100	75-85	60-75	40-60	<40
20	Comprehensive utilization rate of ISW（X_{43}）	85-100	75-85	60-75	40-60	<40
21	Investment intensity of EPT rate（X_{44}）	>800	600-800	400-600	200-400	<200
22	Domestic waste treatment rate（X_{45}）	90-100	80-90	70-80	50-70	<50
23	Domestic wastewater treatment rate（X_{46}）	90-100	80-90	70-80	50-70	<50
24	Comprehensive index of EPT（X_{47}）	>200	150-200	100-150	50-100	<50

Data in table 1 is determined according to *Chinese Environmental Air Quality Standard (GB3095-2000)*, *Surface Water Environmental Quality Standard (GB3838-2002)*, *and Soil Environmental Quality Standard (GB15618-1995),* and *Pilot scheme of ecological comprehensive compensation (2019-1793)* by National Development and Reform Commission.

The evaluation level standard of Payment for ecological services effect of environmental pollution loss is based on the evaluation indicator standard and evaluation results, referring to the latest research results in China and abroad, combined with the development planning and actual situation of China's industrial parks, taking the specific comprehensive evaluation coefficient of Payment for ecological services effect of environmental pollution loss as the grading standard, and subdividing the Payment for ecological services effect of environmental pollution loss They are: excellent [0.9, 1], good [0.8, 90), medium [0.7, 80), qualified [0.6, 70), unqualified [0, 60). According to the requirements of national environmental pollution treatment, the industrial park has raised the level standard of ecological compensation for environmental pollution loss, and implemented the one vote veto system for ecological compensation failing to meet the standard.

2.2 Analysis of traditional niche model

2.2.1 Basic model of traditional niche

According to the theory of ecological economics, niche refers to the position of a population in an ecosystem in time and space and its functional relationship and function with the related population (Godsoe et al., 2017). It represents the minimum threshold of habitat necessary for the survival of every organism in the ecosystem. Niche modeling refers to a mathematical model that uses the niche theory and method to determine the level of Payment for ecological services effect by calculating the niche suitability of evaluation indicators (Julián et al., 2019). Let the ecological factors be expressed as: $x_1(t), x_2(t), \cdots, x_n(t)$, $x_i(t) \in I_i$, I_i is the variation range of the ith ecological factor，it is expressed as：$I_i = [a_i, b_i], (i = 1, 2, \cdots, n)$. Then, the domain of ecological factor can be expressed as: $E = I_1 \times I_2 \times \cdots \times I_n = \Pi_{i=1}^{n} I_i$. E is a subset of n-dimensional ecological factor E^n , if the niche function is a non-negative n-dimensional function: $f(X_i)=f\left(x_1(t),x_2(t),\cdots,x_n(t)\right)$, then niche N of this population can be expressed as:

$$N=\{X_t \mid f(X_i)>0, X_t=\left(x_1(t),x_2(t),\cdots,x_n(t)\right)\},\quad NIE\neq\boldsymbol{\Phi} \qquad (1)$$

According to niche theory, niche suitability interval is (0, 1). The larger the value is, the higher the degree of ecological factors meeting ecological needs is (Mathieu Basille, et al., 2008). The optimum value of ecological factors is denoted as: $X_\alpha=x_1(\alpha),x_2(\alpha),\cdots,x_n(\alpha)$, $X_t\in E$, then; the niche suitability of ecological factors is denoted as：

$$F=\phi\left(X_\alpha,X_t\right),\quad X_\alpha\in N,\quad X_t\in E \qquad (2)$$

According to the different meanings of ϕ, niche suitability functions of regional ecological factors have different connotations. According to relevant theories of ecology, the traditional niche model has niche suitability model (F_t) and limit factor model ($F_{\min-t}$) (Qin Li-li, et al., 2011). The following two basic models of niche evaluation are introduced respectively.

2.2.2 Average operator model (F_t)

If the suitability of regional ecological factors in time period t is expressed as Ft, then the corresponding niche suitability model is expressed as follows：

$$F_t=\frac{1}{n}\sum_{i=1}^{n}\frac{\delta_{\min}+\alpha\times\delta_{\max}}{\delta_{it}+\alpha\times\delta_{\max}}=\frac{1}{n}\sum_{i=1}^{n}\frac{\min\left\{\left|x_i'(t)-x_i'(\alpha)\right|\right\}+\alpha\times\max\left\{\left|x_i'(t)-x_i'(\alpha)\right|\right\}}{\left|x_i'(t)-x_i'(\alpha)\right|+\alpha\times\max\left\{\left|x_i'(t)-x_i'(\alpha)\right|\right\}} \qquad (3)$$

In the type: $\delta_{it}=\left|x_i'(t)-x_i'(\alpha)\right|$, $\left(i=1,2,\cdots,n;t=1,2,\cdots m\right)$

$$\delta_{\max}=\max\left\{\delta_{it}\right\}=\left\{\left|x_i'(t)-x_i'(\alpha)\right|\right\}$$

$$\delta_{\min}=\min\left\{\delta_{it}\right\}=\left\{\left|x_i'(t)-x_i'(\alpha)\right|\right\}$$

α is the model parameter, and the value range of α is :（$0\leq\alpha\leq$）. The calculation results of the model can be adjusted by taking the value of the model parameters according to the changes of environmental conditions, and α =0.5 in the average condition.

2.2.3 Limiting factor model（$F_{\min-t}$）

If the suitability of ecological factors in time period t is expressed as：$F_{\min-t}$, since the minimum value of the factor is taken in the above equation, and the value is limited, it is called the limiting factor model. The specific expression is:

$$F_{\min-t} = \min\{(x_1'(t)/x_1'(\alpha)),(x_2'(t)/x_2'(\alpha)),\cdots,(x_n'(t)/x_n'(\alpha))\} \quad (4)$$

In the above equation, $x_i(t)$ is the measured value of the ith ecological factor, $x_i(\alpha)$ is the optimal value of the ith ecological factor, α is the model parameter, the range and other conditions are the same as above. This model is often used to evaluate the relationship between the most important restrictive factors and their optimal values.

2.3 Construction of comprehensive evaluation model of niche suitability

According to the theory and method of ecological niche, the evaluation indicators is expressed as follows: $x_1, x_2, \cdots, x_{\mathrm{m}}$, Considering the time series of each evaluation indicators, the observed values constitute the ecological vector of m×n dimension : $X_i = (x_{i1}, x_{i2}, \cdots, x_{it})$, $(t = 1, 2, \cdots, n)$. In order to build a comprehensive evaluation model of niche suitability for Payment for ecological services effect, the generalized relevance degree in grey theory is introduced to calculate the niche of ecological factors (Yang K et al., 2018), and the comprehensive evaluation model of niche suitability is constructed by using the weighted evaluation values of absolute niche suitability model and relative niche suitability model. Among them: the absolute niche fitness model is represented by F_t and the relative niche fitness model is represented by. In order to reduce the data distortion caused by shock wave interference, buffer operator is introduced to eliminate the shock wave interference. Let d be the average weakening buffer operator (AWBO) (Li C et al., 2019). The first-order buffer operator of the actual value of ecological factors can be expressed as:

$$X_t D = (x_{1t}, x_{2t}, \cdots, x_{mt}) \cdot d = \frac{1}{n-i+1}(x_{it}, x_{i+1t}, \cdots, x_{mt}), (i = 1, 2, \cdots, m; t = 1, 2, \cdots, n) \quad (5)$$

If D^2 is the second-order weakening buffer operator, then the second-order buffer sequence of the actual value of ecological factor can be expressed as:

$$X_t D^2 = \left(x_{1t}, x_{2t}, \cdots, x_{mt}\right) \cdot d^2 = \frac{1}{n-i+1}\left(x_{it}d + x_{i+1t}d + \cdots + x_{mt}d\right), \cdots \left(i = 1,2,,m; t = 1,2,\cdots,n\right) \quad (6)$$

After the second - order buffer calculation of ecological factors, the data become more stable. In order to effectively evaluate the quality of ecological environment, it is necessary to conduct dimensionless processing on the stationary data of ecological factors, and the value range of the data after processing is between [0,1] (Ali Yousefi and Tang-Tat Ng, 2017). The dimensionless calculation formula is as follows:

$$\begin{cases} x'_{it} = \left(x_{it}d^2\right) / \left(\left(\max x_{it}\right)d^2\right) & (\text{forward pointer}) \\ x'_{it} = 1 - \left(x_{it}d^2\right) / \left(\left(\max x_{it}\right)d^2\right) & (\text{contrary indicator}) \end{cases}, \quad \left(i = 1,2,\cdots,m; t = 1,2,\cdots,n\right) \quad (7)$$

In the above equation, x'_{it} represents the dimensionless value of the ith factor in the t year, and $\max x_{it}d^2$ represents the maximum value of the ith factor in the t year after the second order buffering, and the buffering factor $d = 1/(m-i+1)$. If the optimal fitness of the evaluation indicators is $x_{i\alpha}$, $x'_{i\alpha}$ represents the dimensionless value of the optimal fitness of the ith indicators, then:

$$\begin{cases} x'_{i\alpha} = \left(x_{i\alpha}d^2\right) / \left(\left(\max x_{it}\right)d^2\right) & (\text{forward pointer}) \\ x'_{i\alpha} = 1 - \left(x_{i\alpha}d^2\right) / \left(\left(\max x_{it}\right)d^2\right) & (\text{contrary indicator}) \end{cases}, \quad \left(i = 1,2,\cdots,m; t = 1,2,\cdots,n\right) \quad (8)$$

On the basis of dimensionless processing, null transformation is carried out according to the dimensionless results (Liu HM et al., 2008). The value of null transformation is expressed as follows:

$$\begin{cases} x'_{it}(0) = \left(x'_{1t}(0),\ x'_{2t}(0), \cdots,\ x'_{\mathrm{m}t}(0)\right) = x'_{it} - x'_{1t} \\ x'_{i\alpha}(0) = \left(x'_{1\alpha}(0),\ x'_{2\alpha}(0), \cdots,\ x'_{\mathrm{m}\alpha}(0)\right) = x'_{i\alpha} - x'_{1\alpha} \end{cases} \quad (9)$$

The comprehensive evaluation model of spatial niche suitability is the weighted average of absolute niche suitability model and relative niche suitability model. In order to build a comprehensive evaluation model of spatial niche suitability, it is necessary to build absolute niche suitability ($\varepsilon_{t\alpha}$) measurement model first. The specific model expression is as follows:

$$\varepsilon_{t\alpha} = \frac{1+|S_\alpha|+|S_t|}{1+|S_\alpha|+|S_t|+|S_\alpha - S_t|} \tag{10}$$

$$\begin{cases} S_t = \int_1^n \left(x'_{it}(0) - x'_{i1}(0)\right)\ dt \\ S_\alpha = \int_1^n \left(x'_{i\alpha}(0) - x'_{i1}(0)\right)\ dt \\ |S_t| = \left|\int_1^n \left(x'_{it}(0) - x'_{i1}(0)\right)\ dt\right| = \left|\sum_{k=2}^{n-1} x'_{kt}(0) + \frac{1}{2}x'_{mt}(0)\right| \\ |S_\alpha| = \left|\int_1^n \left(x'_{i\alpha}(0) - x'_{i1}(0)\right)\ dt\right| = \left|\sum_{k=2}^{n-1} x'_{k\alpha}(0) + \frac{1}{2}xx'_{mt}(0)\right| \\ S_t - S_\alpha = \int_1^n \left(x'_{it}(0) - x'_{i\alpha}(0)\right)\ dt \\ |S_t - S_\alpha| = \left|\sum_{k=2}^{n-1}\left(x'_{i\alpha}(0) - x'_{it}(0)\right) + \frac{1}{2}\left(x'_{m\alpha}(0) - x'_{kt}(0)\right)\right| \end{cases}$$

Then, the measurement model of relative niche suitability ($\gamma_{t\alpha}$) is determined by using the data weakened buffer and dimensionless. The specific model expression is as follows：

$$\gamma_{t\alpha} = \frac{1+|S'_\alpha|+|S'_t|}{1+|S'_\alpha|+|S'_t|+|S'_\alpha - S'_t|} \tag{11}$$

$$\begin{cases} S'_t = \int_1^n \left(x''_{it}(0) - x''_{i1}(0)\right)\ dt \\ S'_\alpha = \int_1^n \left(x''_{i\alpha}(0) - x''_{i1}(0)\right)\ dt \\ |S'_t| = \left|\int_1^n \left(x''_{it}(0) - x''_{i1}(0)\right)\ dt\right| = \left|\sum_{k=2}^{m-1} x''_{kt}(0) + \frac{1}{2}x''_{mt}(0)\right| \\ |S'_\alpha| = \left|\int_1^n \left(x''_{i\alpha}(0) - x''_{i1}(0)\right)\ dt\right| = \left|\sum_{k=2}^{m-1} x''_{k\alpha}(0) + \frac{1}{2}x''_{m\alpha}(0)\right| \\ S'_t - S'_\alpha = \int_1^n \left(x''_{it}(0) - x''_{i\alpha}(0)\right)\ dt \\ |S'_t - S'_\alpha| = \left|\sum_{k=2}^{n-1}\left(x''_{k\alpha}(0) - x''_{kt}(0)\right) + \frac{1}{2}\left(x''_{m\alpha}(0) - x''_{kt}(0)\right)\right| \end{cases}$$

Type： $x''_{it}(0) = \left(x''_{1t}(0), x''_{2t}(0), \cdots, x''_{mt}(0)\right) = (x'_{mt})/(x'_{1t}) - 1$, $x''_{i\alpha}(0) = \left(x''_{1\alpha}(0), x''_{2\alpha}(0), \cdots, x''_{m\alpha}(0)\right) = (x'_{m\alpha})/(x'_{1\alpha}) - 1$.

If Ftα is used to represent the comprehensive evaluation model of spatial niche suitability, then：

$$F_{t\alpha} = \theta\varepsilon_{t\alpha} + (1-\theta)\gamma_{t\alpha} \tag{12}$$

Where, θ $(0 \le \theta \le 1)$ is the weighting coefficient, and considering that the importance of the absolute niche suitability and the relative niche suitability are the same, the value of θ is 0.5. When the value is less than 0.5 and tends to 0, the value of the comprehensive niche suitability tends to the relative niche suitability. When the value of θ is greater than 0.5 and tends to 1, the value of comprehensive niche suitability tends to absolute niche suitability.

3. Result

3.1 Collection of research data

In order to verify the validity of the spatial niche model, Nanjing MV Industrial Park is selected as the evaluation object of Payment for ecological services effect. Nanjing MV Industrial Park is located in Jiangning high tech Development Zone, covering an area of 52.98 square kilometers. There are 52 production-oriented enterprises in the park. By the end of 2018, there are 3263200 employees, a total registered capital of 4.2185.6 billion yuan, a total investment of 12.55218 billion yuan, a realized output value of 15.12645 billion yuan, and a profit and tax of 1.5321.8 billion yuan. Nanjing MV Industrial Park was founded in 1998. In 2001, the planned production capacity was realized, with environmental pollution highlighted, and comprehensive environmental treatment work began. According to the statistical data, production and operation data of Nanjing MV Industrial Park and the results of research and investigation, the basic data of 24 evaluation indicators of Nanjing MV Industrial Park from 2011 to 2018 are collected and sorted out in Table 3.

Table 3.Data collection of evaluation indicators of Payment for ecological services effect of Nanjing MV Industrial Park

Criterion layer	Indicators layer	2011	2012	2013	2014	2015	2016	2017	2018
Indicators of	X_{11}	10.3518	10.5728	10.8827	11.2474	12.1829	13.2736	14.9816	16.3217
coordinated	X_{12}	19.87	21.28	22.36	20.41	18.37	25.26	26.28	28.37
economic	X_{13}	10.25	8.38	5.89	7.28	8.32	10.21	9.46	11.36
development	X_{14}	0.9218	0.8928	0.8521	0.7218	0.6927	0.6527	0.5826	0.4981
（X1）	X_{15}	2.1027	2.0527	1.9627	1.8236	1.7528	1..6018	1.5281	1.0827
Indicators of	X_{21}	66.19	66.69	6876	69.28	68.32	70.27	72.08	80.32
ecological	X_{22}	23.78	24.28	24.89	25.18	25.28	26.28	28.32	30.28
compensation	X_{23}	0.7518	0.7629	0.7829	0.8028	0.8218	0.8827	0.8927	0.9126
inputs（X_2）	X_{24}	1.5728	1.6528	1.6829	1.6518	1.7927	1.7538	1.8927	2.0137

Indicators of ecological environmental pollution（X_3）	X_{31}	0.2237	0.1892	0.1728	0.1527	0.1478	0.1327	0.1128	0.0978
	X_{32}	0.1862	1.629	0.1528	0.1328	0.1128	0.0952	0.0813	0.0492
	X_{33}	0.2937	0.2518	0.2038	0.1827	0.1528	0.1237	0.1028	0.0985
	X_{34}	1.2836	1.2134	1.1937	1.1256	1.0736	0.8724	0.6826	0.4825
	X_{35}	283.26	248.25	210.36	183.72	150.57	102.48	78.28	49.54
	X_{36}	213.39	182.28	150.37	120.28	107.39	82.29	65.35	50.32
	X_{37}	110.38	98.28	73.29	59.38	52.39	50.27	49.29	48.32
	X_{38}	253.92	221.39	198.29	178.25	148.27	98.28	70.28	58.29
Indicators of environmental pollution treatment（X_4）	X_{41}	66.28	68.37	70.27	72.39	74.39	75.62	78.39	86.28
	X_{42}	70.28	74.28	76.29	78.36	77.28	78.38	79.38	80.38
	X_{43}	69.78	72.49	74.82	77.29	79.38	80.73	82.39	84.29
	X_{44}	550.28	610.28	685.32	700.86	758.29	798.28	825.38	927.39
	X_{45}	68.39	69.38	71.29	75.38	78.38	82.38	89.32	91.02
	X_{46}	75.28	79.37	82.39	85.28	87.38	89.27	90.27	91.67
	X_{47}	182.38	175.28	168.38	145.28	96.37	78.28	51.28	4.38

3.2 Technical treatment of application of evaluation indicators

The technical treatment of evaluation indicators includes second-order buffer processing and dimensionless processing, which is the basic work of comprehensive evaluation of Payment for ecological services effect of environmental pollution loss. According to the research design, the following contents are analyzed and explained.

(1) Second-order buffer processing of evaluation indicators. The purpose of buffer calculation is to improve the change stability of evaluation indicators. For the basic data in Table 1, the second-order buffer correction formula (5) and (6) of evaluation indicators are used for buffer calculation, so as to eliminate the large fluctuation in the original data, make the data more stable, and improve the effectiveness of the comprehensive evaluation results of Payment for ecological services effect of environmental pollution loss in Nanjing MV Industrial Park. According to the above research design, the second-order buffer processing is carried out for the evaluation indicators by using the buffer calculation model, and the specific buffer calculation results are shown in Table 4.

Table 4.The second-order buffer processing results of Payment for ecological services effect evaluation indicators of Nanjing MV Industrial Park

No.	Indicators	2011	2012	2013	2014	2015	2016	2017	2018
1	X_{11}	11.0527	11.7328	11.9857	12.2175	12.5283	12.8361	14.2175	15.7528
2	X_{12}	20.68	21.87	22.18	21.98	20.25	24.18	25.19	27.78
3	X_{13}	11.16	9.17	7.06	7.54	8.96	10.38	9.76	11.18
4	X_{14}	0.9116	0.8825	0.8426	0.7516	0.7126	0.6847	0.6019	0.5052
5	X_{15}	2.0825	2.0425	1.9826	1.8837	1.7925	1..6814	1.5681	1.1054
6	X_{21}	68.12	67.62	68.36	68.78	68.52	70.12	71.97	80.01
7	X_{22}	24.75	25.26	25.79	25.98	26.15	26.21	27.62	30.17
8	X_{23}	0.7612	0.7678	0.7803	0.7978	0.8198	0.8787	0.8868	0.9078
9	X_{24}	1.5812	1.6037	1.6538	1.6428	1.7738	1.7602	1.8862	2.007
10	X_{31}	0.2152	0.1878	0.1776	0.1521	0.1488	0.1346	0.1168	0.1032
11	X_{32}	0.1802	1.603	0.1516	0.1326	0.1129	0.0963	0.0825	0.05128
12	X_{33}	0.2833	0.2448	0.2018	0.1826	0.1537	0.1243	0.1034	0.0997
13	X_{34}	1.2721	1.2044	1.1827	1.1246	1.0746	0.8764	0.6887	0.4865
14	X_{35}	272.28	228.46	205.45	171.65	148.56	105.42	78.47	49.68
15	X_{36}	202.35	189.58	148.35	116.67	106.54	82.41	65.46	50.67
16	X_{37}	108.36	96.78	72.21	59.48	52.49	50.62	49.53	48.71
17	X_{38}	233.12	211.76	188.25	170.65	142.27	99.21	73.28	59.05
18	X_{41}	68.28	68.87	70.31	72.36	74.41	75.65	78.29	85.78
19	X_{42}	69.78	72.48	76.69	78.25	76.78	78.06	78.88	80.02
20	X_{43}	71.72	72.68	74.98	77.21	79.08	80.06	81.89	84.79
21	X_{44}	560.45	620.14	689.78	700.04	749.78	789.78	806.78	912.54
22	X_{45}	70.57	70.18	70.98	73.37	77.38	81.58	87.78	90.48
23	X_{46}	76.29	80.16	82.46	85.21	88.88	88.65	89.87	91.02
24	X_{47}	162.47	161.22	166.34	141.22	96.47	78.78	51.84	4.84

(2) Dimensionless processing of evaluation indicators. Dimensionless refers to the behavior or process of removing part or all of the dimensionality of the physical quantity of the evaluation indicators by selecting appropriate substitute variables. The most commonly used dimensionless processing is normalization, that is, to merge all the values of the evaluation indicators into [0, 1] by certain methods. In view of the difference between positive indicators and reverse indicators, the merging principle of the positive indicators is the maximum of 1 and the minimum of 0; the merging principle of the reverse indicators is the opposite of the positive indicators, the minimum of 1 and the maximum of 0. In the dimensionless processing of the actual evaluation indicators, the maximum and minimum values can be selected according to

different evaluation requirements. The dimensionless calculation formula (7-8) is used for dimensionless calculation of the basic data after the second-order buffer processing. In the normalization process, the maximum value and the minimum value of the evaluation indicators are used for calculation. See Table 5 for the calculation results.

Table 5.Dimensionless processing results of Payment for ecological services effect evaluation indicators of Nanjing MV Industrial Park

No.	Indicators	2011	2012	2013	2014	2015	2016	2017	2018
1	X11	0.6432	0.6828	0.6975	0.7110	0.7291	0.7470	0.8274	0.9168
2	X12	0.6898	0.7295	0.7398	0.7332	0.6755	0.8065	0.8402	0.9266
3	X13	0.9140	0.7510	0.5782	0.6175	0.7338	0.8501	0.7993	0.9156
4	X14	0.8219	0.8428	0.8518	0.8628	0.8728	0.8837	0.8926	0.9089
5	X15	0.8219	0.8329	0.8428	0.8528	0.8729	0.8818	0.8838	0.9102
6	X21	0.7832	0.7774	0.7859	0.7908	0.7878	0.8062	0.8274	0.9199
7	X22	0.7388	0.7540	0.7699	0.7755	0.7806	0.7824	0.8245	0.9006
8	X23	0.7639	0.7705	0.7830	0.8006	0.8227	0.8818	0.8899	0.9110
9	X24	0.7187	0.7290	0.7517	0.7467	0.8063	0.8001	0.8574	0.9123
10	X31	0.7829	0.7939	0.8028	0.8128	0.8329	0.8539	0.8839	0.9128
11	X32	0.7729	0.7839	0.7938	0.8048	0.8279	0.8478	0.8793	0.9027
12	X33	0.7927	0.7998	0.8238	0.8305	0.8478	0.8639	0.8875	0.9098
13	X34	0.7827	0.7937	0.8238	0.8483	0.8667	0.8798	0.8953	0.9128
14	X35	0.7729	0.7902	0.8037	0.8314	0.8419	0.8538	0.8896	0.9038
15	X36	0.7562	0.7739	0.7948	0.8139	0.8348	0.8539	0.8689	0.8973
16	X37	0.7782	0.7927	0.8218	0.8427	0.8638	0.8837	0.9027	0.9178
17	X38	0.7829	0.8027	0.8261	0.8389	0.8528	0.8638	0.8729	0.8928
18	X41	0.7264	0.7327	0.7480	0.7698	0.7916	0.8048	0.8329	0.9126
19	X42	0.7269	0.7550	0.7989	0.8151	0.7998	0.8131	0.8217	0.8535
20	X43	0.7318	0.7416	0.7651	0.7879	0.8069	0.8169	0.8356	0.8952
21	X44	0.5899	0.6528	0.7261	0.7369	0.7892	0.8313	0.8492	0.9606
22	X45	0.7128	0.7089	0.7170	0.7411	0.7816	0.8240	0.8867	0.9139
23	X46	0.7785	0.8180	0.8414	0.8695	0.9069	0.9046	0.9170	0.9288
24	X47	0.8219	0.8528	0.8629	0.8728	0.8827	0.8936	0.0912	0.9167

3.3 evaluation results of Payment for ecological services effect of environmental pollution loss

The comprehensive evaluation of the Payment for ecological services effect of environmental pollution loss in Nanjing MV Industrial Park is divided into two levels: criterion layer and target layer. According to the above research design, it is carried out the following comprehensive evaluation application analysis of the two levels on Payment for ecological services effect of environmental pollution loss comprehensive evaluation application analysis:

(1) Comprehensive evaluation of Payment for ecological services effect in the criterion layer. Comprehensive evaluation of Payment for ecological services effect in the criterion layer takes the coordinated economic development, ecological compensation, ecological environmental pollution and environmental pollution treatment of the industrial park as the evaluation object. Using the above model and the corresponding evaluation indicators of the four Payments for ecological services effect evaluation objects in the criterion layer, the absolute niche suitability, relative niche suitability and spatial niche suitability of the comprehensive evaluation objects are calculated respectively. According to the calculation results of niche suitability, the Payment for ecological services effect of the evaluation object in the criterion layer is judged. When calculating the spatial niche suitability model, a = 0.65 is selected. This ratio parameter is determined according to the empirical data of Nanjing MV Industrial Park. See Table 6 for the specific calculation results.

Table 6.Comprehensive evaluation results of Payment for ecological services effect of criterion layer

Evaluation method	Indicators	2011	2012	2013	2014	2015	2016	2017	2018
	X_1	0.7586	0.7782	0.8094	0.8299	0.8400	0.8574	0.8743	0.9112
	X_2	0.7386	0.7528	0.7835	0.8092	0.8254	0.8422	0.8676	0.9017
$\varepsilon_{t\alpha}$	X_3	0.6678	0.6876	0.6924	0.7175	0.7386	0.7617	0.7816	0.8472
	X4	0.7556	0.7733	0.7990	0.8095	0.8235	0.8585	0.8658	0.9264
	X1	0.6834	0.7166	0.7285	0.7528	0.7854	0.8027	0.8376	0.8912
	X2	0.6395	0.6613	0.6953	0.7356	0.7641	0.7873	0.7910	0.8817
$\gamma_{t\alpha}$	X3	0.6365	0.6572	0.6731	0.6987	0.7237	0.7437	0.7658	0.8046
	X4	0.6751	0.6932	0.7218	0.7562	0.7839	0.8137	0.8374	0.8762
	X1	0.7323	0.7566	0.7811	0.8029	0.8209	0.8383	0.8615	0.9042
	X2	0.7039	0.7208	0.7526	0.7834	0.8039	0.8230	0.8408	0.8947
$F_{t\alpha}$	X3	0.6568	0.6770	0.6856	0.7109	0.7334	0.7554	0.7761	0.8323
	X4	0.7274	0.7453	0.7720	0.7908	0.8096	0.8428	0.8559	0.9088

(2) Comprehensive evaluation of Payment for ecological services effect in target layer. The comprehensive evaluation of the Payment for ecological services effect of the target layer takes Payment for ecological services effect of Nanjing MV Industrial Park as the evaluation object. In the same way, the absolute niche fitness, relative niche fitness and spatial niche fitness of the

evaluation object are calculated by using the above model. According to the comprehensive analysis results, a = 0.65 is selected, and the specific calculation results are shown in Table 7.

Table7. Comprehensive evaluation results of Payment for ecological services effect of target layer

Evaluation method	2000	2011	2012	2013	2014	2015	2016	2017	2018
$\varepsilon_{t\alpha}$	0.7063	0.7302	0.7480	0.7711	0.7915	0.8069	0.8300	0.8473	0.8966
$\gamma_{t\alpha}$	0.6268	0.6586	0.6821	0.7047	0.7358	0.7643	0.7869	0.8080	0.8634
$F_{t\alpha}$	0.6785	0.7051	0.7249	0.7479	0.7720	0.7920	0.8149	0.8335	0.8850

4. Discussion

4.1 Evaluation level change rule and problems found

In order to analyze change rule of evaluation results and the existing problems, effective improvement strategies are formulated according to the analysis results, it is drawn in the rectangular coordinate system the change rule chart of the evaluation level of the Payment for ecological services effect of environmental pollution loss in the criterion layer. See Figure 1 for the specific change rule and interrelation between evaluation results of the four indicators.

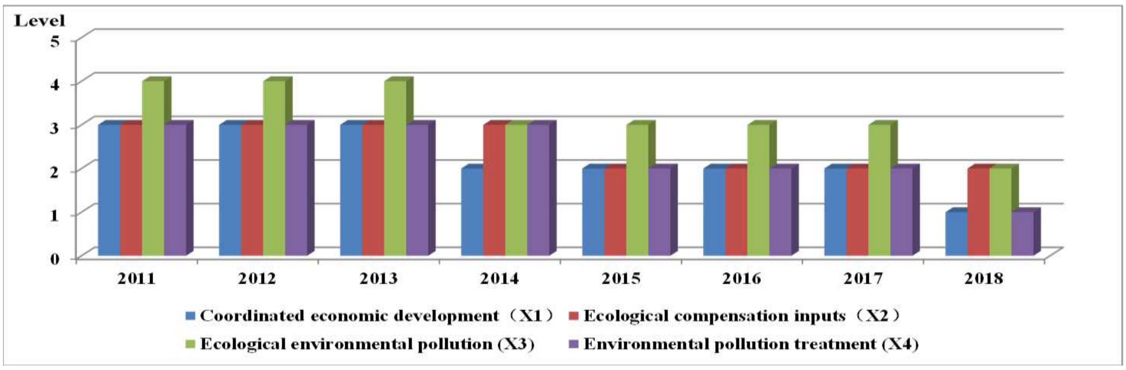

Fig.1. Change rule and interrelation of evaluation levels of ECE of EPL in Nanjing MV Industrial Park

According to the evaluation results of the Payment for ecological services effect of environmental pollution loss in criterion layer of Nanjing MV Industrial Park, the evaluation level coordinated economic development in 2011 is level Ⅲ belonging to the ordinary level, and rises to level I belonging to the excellent level in 2018; the evaluation level of ecological compensation inputs in 2011 is level Ⅲ belonging to the ordinary level, and rises to level Ⅱ belonging to good level; the evaluation level of ecological environmental pollution is level IV belonging to qualified level in 2011, and rises to level II belonging to good level in 2018; the evaluation level of environmental pollution treatment is level III belonging to ordinary level in 2011, and rises to level I belonging to excellent level in 2018. From the above evaluation results, it can be seen that the Payment for ecological services effect of environmental pollution loss in Nanjing MV Industrial Park is generally good, indicating that the economic development of the industrial park is relatively good, with much attention paid to environmental pollution treatment. However, belonging to good level, ecological compensation inputs and ecological environmental pollution are still not ideal, and the main problems faced by Nanjing MV Industrial Park, which need to be further strengthened.

4.2 Implementation effect of Payment for ecological services system and the problems found

Nanjing MV Industrial Park has implemented a comprehensive Payment for ecological services system for environmental pollution loss since 2018. In order to analyze the implementation effect of the Payment for ecological services system, the evaluation results of the absolute niche model, the relative niche model and the spatial niche suitability model are drawn in the rectangular coordinate system. From the trend chart of the evaluation results, it can be seen that the Payment for ecological services effect is significantly improved. See table 2 for the specific variation trend and the interrelation.

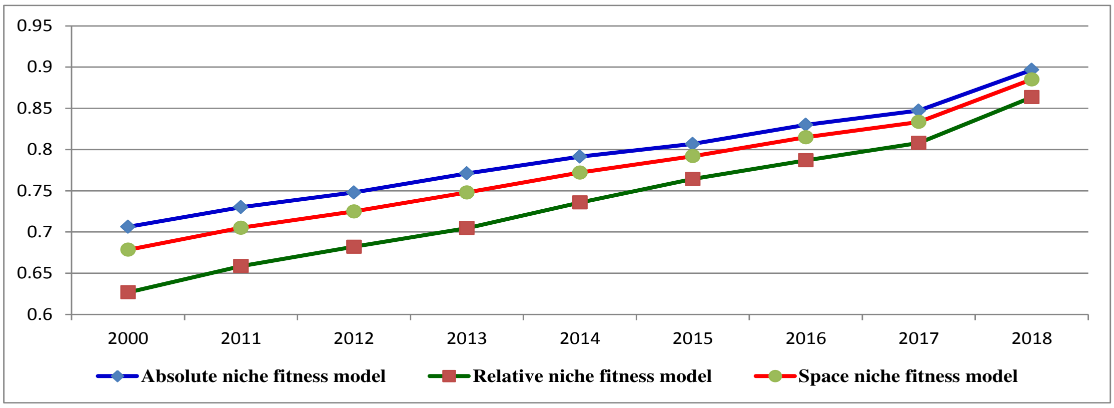

Fig.2. Change trend and interrelation chart of evaluation results of different evaluation models

From the comparative analysis of the evaluation results of the Payment for ecological services effect in Nanjing MV Industrial Park, it can be seen that the Payment for ecological services effect in 2018 is significantly improved compared with any year before 2018, that is, the Payment for ecological services effect of the environmental pollution loss in Nanjing MV Industrial Park has had obvious effect, indicating that certain effect has been brought by the implementation of the Payment for ecological services system. Of course, the Payment for ecological services for environmental pollution loss in Nanjing MV Industrial Park is a long-term task. It needs a long-term process to verify the effectiveness of the implementation of the Payment for ecological services system. The research of Payment for ecological services for environmental pollution loss in Nanjing MV industrial park still needs to be deepened, so as to gradually improve the Payment for ecological services system and promote the gradual formation of "U" turning trend of environmental pollution in Nanjing MV Industrial Park.

5. Conclusions

In order to study comprehensive evaluation of Payment for ecological services effect of environmental pollution loss in Nanjing MV Industrial Park, this paper put forward spatial niche suitability model for the first time. On the basis of literature review, theoretical analysis, questionnaire survey and expert evaluation, the latest research results in China and abroad were used for reference, with it fully considered the actual situation and requirements of comprehensive evaluation of Payment for ecological services effect of environmental pollution loss in industrial parks. On the basis of the traditional niche suitability model, spatial suitability model was constructed through improvement and innovation, and the comprehensive evaluation and application research on Payment for ecological services effect of environmental pollution loss in

Nanjing Industrial Park was carried out. Through comparative analysis of the evaluation results, some problems in the Payment for ecological services management of environmental pollution loss of industrial park were found out and further explored. The conclusions are as follows:

First of all, the Payment for ecological services effect of environmental pollution loss in Nanjing MV Industrial Park is on the rise as a whole, but the Payment for ecological services effect in the criterion layer is imbalanced. This is mainly reflected in: level of Payment for ecological services inputs and the level of ecological environmental pollution are lower than that of coordinated economic development and environmental pollution treatment, indicating that there is deviation in Payment for ecological services management.

Secondly, the Payment for ecological services effect of Nanjing Industrial Park is obviously improved after implementation of the Payment for ecological services system of environmental pollution loss. By comparing the evaluation results before and after the implementation of the Payment for ecological services system, it is found that the Payment for ecological services effect in 2018 is significantly higher than that in other years, which indicates implementation effectiveness of the Payment for ecological services system.

Finally, through comparing the evaluation results of spatial niche suitability model with those of absolute niche model and relative niche model, it is found that the evaluation results of spatial niche model are relatively stable and more in line with the actual situation of Nanjing MV Industrial Park, which shows that the evaluation model constructed in this paper is more effective.

Abbreviation

PES: payment for ecological services; ECEE: ecological services effect evaluation; EPL: environmental pollution loss; NFM: niche suitability model; SNSM: spatial niche suitability model; MV

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Competing interests

Author 1 is a distinguished professor of the school of management of Nanjing University of posts and telecommunications, and Author 2 is a postgraduate student of the school of economics and management of Dalian university of technology. The two authors participated in the research results of the national social science foundation project (19BJL015), and completed this paper in collaboration, without any conflict of interest with any individual or organization.

Authors' contributions

Xiuyan Han performed the majority of experiments, data evaluations and was a major contributor in editing the manuscript; Tianyi Cao contributed on field sampling and sample analysis etc.

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Availability of data and materials

The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Consent for publication

All authors agreed to publish the paper.

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Figures

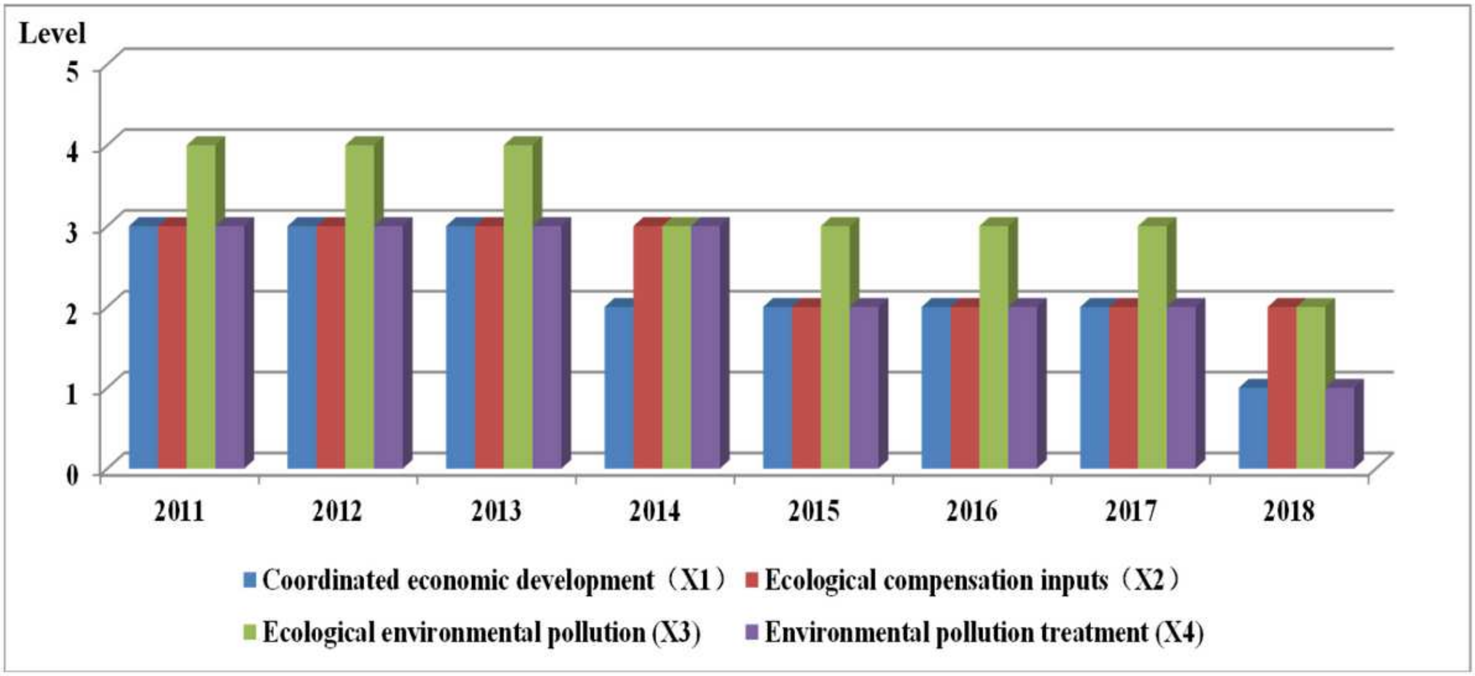

Figure 1

Change rule and interrelation diagram of evaluation grade of ECE of EPL in Nanjing MV Industrial Park

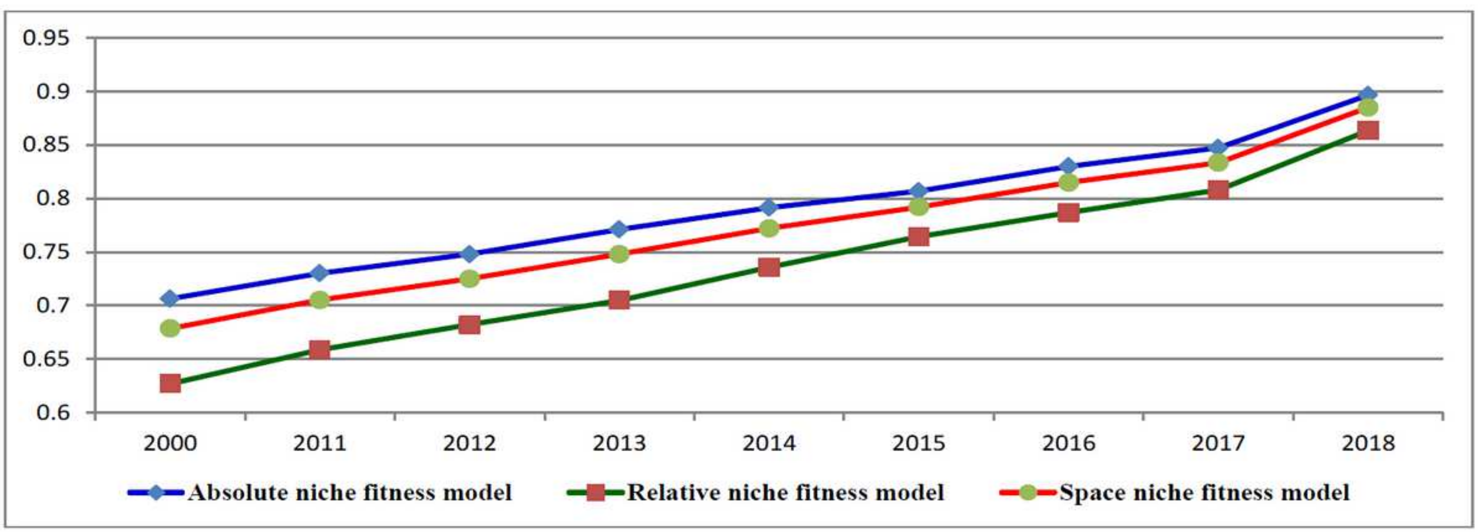

Figure 2

Change trend and interrelation chart of evaluation results of different evaluation models

Supplementary Files

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