Study on the Evaluation of Ecological Compensation Effect for Environmental Pollution Loss from Energy Consumption: Taking Nanjing MV Industrial Park as an Example

Xiuyan Han (✉ hanxy2015@163.com)

Qufu Normal University Rizhao Campus <https://orcid.org/0000-0002-1860-1977>

Tianyi Cao

Dalian University of Technology

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Study on the Evaluation of Ecological Compensation Effect for Environmental Pollution Loss from Energy Consumption: Taking Nanjing MV Industrial Park as an Example

Xiuyan Han^{a*}, Tianyi Cao^b

^a School of Economics, Qufu Normal University, Rizhao 276826, China

^b School of Economics and Management, Dalian University of Technology, Dalian, Liaoning 116024 China

Abstract: In order to explore the effective method of the ecological compensation effect evaluation (ECEE) of the environmental pollution loss (EPS) in the industrial parks, based on the literature review and the current situation analysis, this paper selected four kinds of 26 evaluation indicators to build the evaluation indicators system. The spatial niche suitability model (SNSM) is reconstructed after analysis and improvement. Then, taking Nanjing MV Industrial Park as an example, SNSM and related research data were used to perform an application test of ecological compensation effect evaluation. The evaluation results showed that although the ecological compensation effect of the Nanjing MV industrial park's environmental pollution loss showed an upward trend in 2011-2018, the upward situation showed an imbalance. The effect of ecological environment compensation input status and ecological environment pollution status is significantly lagging behind. They are still the focus of future work of Nanjing MV Industrial Park. The research proved that the niche suitability model's evaluation results conform to Nanjing MV Industrial Park's actual situation. This paper's research results provide an effective quantitative analysis method for the management of ecological compensation effects in industrial parks and the improvement of ecological compensation effects.

Keyword: Ecological compensation effect; comprehensive evaluation; SNSM; environmental pollution loss; industrial parks

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Authors: Xiuyan Han (1974-) , Women, Born in Jiamusi of Heilongjiang province. Associate professor and doctor of management, School of economics, Qufu Normal University, research direction: energy and environmental management; Tianyi Cao (1998-) , Women, Born in Jiamusi of Heilongjiang province, master degree candidate, Faculty of Economics and Management of Dalian University of Technology. Research direction: Environmental Finance.

Corresponding author Xiuyan Han, E-mail: hanxy2015@163.com; Tel.: +86-139-1301-6016

1. Introduction

The development of China's industrial parks not only promotes the rapid economic growth, but also produces environmental pollution to a certain extent. The evaluation of ecological compensation effect of environmental pollution loss has been raised, and gradually becomes a major problem that needs to be solved (Han et al, 2019). For a long time, the problem of ecological compensation for environmental pollution loss in China's industrial parks has not been paid enough attention to, so the environmental pollution level of industrial parks has been kept at a high level. The deepening of environmental pollution will have a significant impact on the compensation effect of environmental pollution loss, ecological environment quality and sustainable development of industrial parks (Wang et al., 2019). Meanwhile, the deepening of environmental pollution will also pose a threat to people's living environment, quality of life, health and even life to some extent (Yang et al., 2019). Therefore, it is particularly important and urgent to study the evaluation method and application of ecological compensation for environmental pollution loss in industrial parks.

Overseas research on ecological compensation effect evaluation started early. In 1910, American scholar Johnson first proposed the concept of niche. In the early 1920s, Gri-nell first proposed and used the niche method in 1924. Charles Elton developed the niche method in 1927, which is mainly used to analyze ecological conditions (Barry et al., 1980). In the late 1970s, the concept of "service of nature" was first put forward by theorists, advocating that environmental polluters should make economic compensation for ecological damage (Westman et al., 1997). In the mid-1980s, the nomadic pastoralist areas in the western United States had a certain degree of damage to the ecosystem due to energy extraction and utilization, so ecological compensation effect evaluation and its application began to be studied (Coughenour et al., 1985); In the early 1990s, the NOAA emergency valuation team conducted an

assessment study on the environmental pollution and its pollution losses in American ocean and atmosphere, constructed an evaluation model, and reached valuable evaluation conclusions (Arrow et al., 1993). 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, 1997). Kelly (2007) used the niche model to evaluate the ecological risks of forests in the United States. According to the latest research results, overseas evaluation of ecological compensation effect is developing towards the direction of multiple standards and technologies (Martín-López et al., 2019). The evaluation of ecological compensation effect involves more and more contents, including: road environmental pollution payment (Cuperus et al, 1996), ecological compensation of damaged watershed (Loomis et al., 2000) Rural ecological compensation (Geussens et al., 2019), land pollution ecological compensation (Loft et al., 2019), etc. In the specific evaluation process, scholars considered that the ecological compensation effect of environmental pollution loss should be evaluated in combination with social benefits (Grima et al., 2018), and the cost-effectiveness of ecological compensation mode (Liu et al., 2020) as well as environmental protection and poverty reduction objectives should be fully considered (Ola et al., 2019). It can be seen that the evaluation of ecological compensation effect in foreign countries is earlier than that in China, and a relatively systematic system of theories and methods has been formed.

The Chinese scholars' research on the evaluation of ecological compensation effect began in the early 21st century, more than 20 years later than that of developed countries. Most of the studies were based on the research results and experience of overseas countries, and the theories and methods of the ecological compensation effect of environmental pollution loss suitable for China's national conditions are in urgent need of research (Xu and Li, 2015). In China, Deng et al. (2001) first proposed that ecological

compensation should be integrated into China's environmental impact assessment; Wang and Xu (2008) studied how to introduce ecological compensation into the environmental impact and explored its application in combination with the actual situation. Since 2010, with the rapid development of China's ecological industrial parks, more and more research results have been made on the effect of ecological compensation and the system of ecological compensation in China, mainly focusing on agriculture, grassland, water area, forest, electricity, etc. China's theorists' research on regional ecological compensation started in the early 21st century (Du 2001), and the research on Industrial Park ecological compensation started in 2013 (Wang et al., 2013). Relevant research results are as follows: Shen et al. (2018) analyzed the performance of ecological compensation in the ecological barrier area, studied the evaluation method and application of ecological performance; Jin 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 et al. (2019) took the ecological compensation of Xilin Gol grassland as an example, studied the impacting performance of ecological compensation performance, and explored effective ways to improve ecological compensation performance. There are still many studies in China that focus on environmental pollution and ecological compensation in urbanization. (Han et al., 2018, 2019; Liu et al., 2020); Some researchers used niche models to evaluate urban forest landscape quality (Han et al., 2021).

From the above literature review, research on the evaluation of ecological compensation effects at home and abroad is in the development stage, and the overseas ecological compensation effect evaluation adopts the name of "ecosystem service payment". Although the theory and method system of ecological compensation effect evaluation has formed, due to differences in social systems, ecological compensation concepts, and compensation subjects, the theories and methods of ecological compensation effect evaluation

cannot be directly applied in China. In China, there are relatively few research results on ecological compensation and evaluation of ecological compensation effect. Most of the research on this problem is not in-depth, and the existing research results cannot meet the needs of the practice of evaluating the effect of ecological compensation for environmental pollution losses in China's industrial parks, and there is an urgent need for scientific and effective methods for evaluating the effects of ecological compensation for environmental pollution losses and application examples. Therefore, it is very important and urgent to study the comprehensive evaluation method and its application of ecological compensation effect of environmental pollution loss in Nanjing MV Industrial Park.

2. Materials and Methods

2.1 Construction of evaluation indicators system and definition of evaluation standard

2.1.1 Selection of evaluation indicators and construction of evaluation indicators system

In order to achieve the comprehensive evaluation of the ecological compensation effect of environmental pollution loss in industrial parks, it is necessary to select the comprehensive evaluation indicators to build the evaluation indicators system of the ecological compensation effect of environmental pollution loss in industrial parks (Bundy et al., 2019). Based on comprehensive analysis, fully consider the actual situation of ecological compensation for environmental pollution loss in China's industrial parks, according to the requirements of the "Evaluation Method of Ecological Compensation Effect for Environmental Pollution Treatment of Nanjing MV Industrial Park" and the latest research results of China's experts (Guo and Li, 2014; Gong and Chen, 2019; Teng, 2020), economic effect, ecological compensation, ecological environmental pollution, and ecological environmental pollution treatment were selected, with a total of 26 comprehensive evaluation indicators. These evaluation indicators comprehensively reflect the ecological compensation effect of pollution treatment in industrial parks. According to the selected specific

evaluation indicators, the comprehensive evaluation indicators system of ecological compensation effect for the environmental pollution treatment in industrial parks is set up in Table 1.

Table 1 Comprehensive evaluation indicators system of ECEE of energy consumption pollution treatment in Nanjing MV Industrial Park

Target layer	Criterion layer	Measure's layer	Unit	Indicator's properties
Comprehensive evaluation of ecological compensation effect of environmental pollution treatment in Industrial Parks	Indicators of economic effect (X ₁)	Per capita gross output value (X ₁₁)	10000yuan/p	forward pointer
		Return on equity (X ₁₂)	%	forward pointer
		Energy consumption intensity (X ₁₃)	ton/10000yuan	contrary indicator
		Proportion of fiscal investment in EEC (X ₁₄)	%	forward pointer
		Investment intensity of ecological restoration (X ₁₅)	10000yuan/km ²	forward pointer
		IEPT / total output value (X ₁₆)	%	forward pointer
	Indicators of ecological compensation (X ₂)	Ecological environment index (X ₂₁)	%	forward pointer
		Environmental greening rate (X ₂₂)	%	forward pointer
		Standard rate of ecological compensation (X ₂₃)	%	forward pointer
		Ecological landscape index (X ₂₄)	%	forward pointer
		Standard rate of resource compensation (X ₂₅)	%	forward pointer
		Percentage of "Green Certified" Enterprises in the Park (X ₂₆)	%	forward pointer
	Indicators of ecological environmental pollution (X ₃)	Compensation rate of EPL (X ₃₁)	mg/m ³	forward pointer
		EC CO ₂ emission intensity (X ₃₂)	ton/10000yuan	contrary indicator
		IWG emission intensity (X ₃₃)	mg/m ³	contrary indicator
		IWW emission intensity (X ₃₄)	mg/m ³	contrary indicator
		Emission intensity of solid waste (X ₃₅)	10000ton/km ²	contrary indicator
		Air pollution index (X ₃₆)	%	contrary indicator
	Indicators of ecological environmental pollution treatment (X ₄)	Water pollution index (X ₃₇)	%	contrary indicator
		Land pollution index (X ₃₈)	%	contrary indicator
		Standard rate of IWW treatment (X ₄₁)	%	forward pointer
		Standard rate of IWG emission treatment (X ₄₂)	%	forward pointer
		Comprehensive utilization rate of ISW (X ₄₃)	%	forward pointer
		Domestic waste treatment rate (X ₄₄)	%	forward pointer
		Domestic wastewater treatment rate (X ₄₅)	%	forward pointer
		Comprehensive index of EPT (X ₄₆)	%	forward pointer

EEC: Ecological Environment Compensation; IEPT: Investment in environmental pollution treatment; EPL: Environmental Pollution Loss; EC: Energy Consumption; IWG: Industrial Waste Gas; IWW: Industrial waste water; ISW: Industrial Solid Waste; . EPT: Environmental Pollution Treatment.

The above four types of indicators constitute a comprehensive evaluation indicators system of ECEE of energy consumption pollution treatment in Nanjing MV Industrial Park. The indicators of economic effect reflect the status of the impact of environmental pollution loss ecological compensation on the economic effect. Environmental pollution treatment and ecological compensation do not affect the economic effect is the basic requirement, so that this paper selected indicators of per capita gross output value and return on equity; Energy consumption intensity is the ratio of energy consumption to the total industrial output value of the same caliber. It is an contrary indicator and strives to reduce energy consumption without reducing the total industrial output value; the proportion of fiscal investment in ecological environment compensation refers to the proportion of fiscal funds in the total investment for ecological restoration and environmental pollution treatment of the industrial park; investment intensity of ecological restoration refers to the required amount of investment in restoration or improvement of ecological quality per square kilometer in an industrial park; "IEPT / total output value" refers to the ratio of the total investment in environmental pollution treatment of the park in the fiscal year to the total industrial output value in the same period; indicators of ecological compensation reflects the ecological quality status of the industrial park, and ecological environment index is the ratio of the ecological index during the reporting period to the same index in a fixed period. This article used the average value of the land ecological index, water ecological index, and air ecological index to measure ecological environmental status, and the data is from the results calculated by the park management committee; the environmental greening rate is the ratio of the green area in the park to the total area; the standard rate of ecological compensation refers to the ratio of the amount of ecological compensation (or the number of projects that meet the standard) to the total ecological compensation standard (the total number of ecological compensation projects); the ecology landscape index refers to the ratio of the current value of

the main landscape index to the value of the previous period. The average value of the landscape diversity index, landscape richness index, landscape evenness index, landscape aggregation index and landscape naturalness index in the evaluation is used to measure ecology landscape status; the rate of resource compensation compliance refers to the ratio of the total amount of funds that have been compensated for main resource consumption or pollution in the park to the total amount of compensation that should be compensated according to the standard. Consumption of energy and polluted water and land resources; the percentage of "green certification" enterprises in the park refers to the ratio of the number of enterprises that have passed the prescribed green certification to the total number of enterprises; the indicators of ecological environment pollution reflects the degree of ecological environmental degradation, the compensation rate of EPL is the ratio of the total value of compensation for various forms of environmental pollution treatment and restoration in the park to the total environmental pollution loss measurement caused by energy consumption and pollution; energy consumption CO₂ emission intensity refers the ratio of the park energy consumption CO₂ emissions to the total output value in the same period in the fiscal year; industrial waste gas emission intensity, industrial wastewater emission intensity, and emission intensity of solid waste are the ratios between the actual emissions of waste gas, wastewater, and solid waste and the emission standards. The emissions of multiple pollutants are calculated by weighted average; the air pollution index, water pollution index and land pollution index are the ratios of the pollution index of the current period to the pollution index of the previous period. Multiple Pollutions are calculated using the weighted average method, and this article used the pollution indexes calculated by the park; the indicators of ecological environmental pollution treatment reflect the effect of environmental pollution restoration. The standard rate of IWW treatment and the standard rate of IWG emission treatment are the degrees to which the corresponding pollution index reaches the required standard; the comprehensive

utilization rate of ISW refers to the ratio of the solid waste discharged by industrial production that can be fully utilized and generate value to the total discharge; the domestic waste treatment rate refers to the ratio of the waste discharged by the employees in the park and reach the degree of pollution-free through treatment; the domestic wastewater treatment rate refers to the ratio of the wastewater discharged by the employees in the park and reaches the degree of pollution-free through treatment; the comprehensive index of EPT refers to the weighted average of the air pollution index, water pollution index and land pollution index of the park, and the data is from the results calculated by the industrial park.

2.1.2 Collection of research data

In order to explain the evaluation method of the ecological compensation effect of environmental pollution loss in Industrial Park, MV Industrial Park in Nanjing was selected as the evaluation object of the ecological compensation effect. Nanjing MV Industrial Park is located in Jiangning High-tech Development Zone, covering 52.98 square kilometers. There are 52 production-oriented enterprises in the park. By the end of 2018, there were 3,263,200 employees, total registered capital of 4.21856 billion yuan, a total investment of 12.55218 billion yuan, a realized output value of 15.12645, and a tax of 1.5321.8 billion yuan. Nanjing MV Industrial Park was founded in 1998. In 2001, the planned production capacity was realized, and comprehensive environmental treatment work began since the environmental pollution situation was highlighted. According to the statistical data, production and operation data, and the research and investigation results of Nanjing MV Industrial Park, the basic data of 26 comprehensive evaluation indicators of Nanjing MV Industrial Park from 2011 to 2018 are collected and sorted out in Table 2.

Table 2 Date collection table of the comprehensive evaluation indicators system of ECEE of energy consumption pollution treatment in Nanjing MV Industrial Park

Criterion layer	Measure's layer	2011	2012	2013	2014	2015	2016	2017	2018
Indicators of economic effect (X ₁)	X ₁₁	10.3518	10.5728	10.8827	11.2474	12.1829	13.2736	14.9816	16.3217
	X ₁₂	19.87	21.28	22.36	20.41	18.37	25.26	26.28	28.37
	X ₁₃	0.9218	0.8928	0.8521	0.7218	0.6927	0.6527	0.5826	0.4981
	X ₁₄	46.68	46.96	47.05	47.37	47.65	48.96	48.56	48.06
	X ₁₅	375	371	388	398	432	438	446	450
	X ₁₆	1.5728	1.6528	1.6829	1.6518	1.7927	1.7538	1.8927	2.0137
Indicators of ecological compensation (X ₂)	X ₂₁	91.38	98.74	111.96	132.15	142.18	158.76	178.38	176.67
	X ₂₂	23.78	24.28	24.89	25.18	25.28	26.28	28.32	30.28
	X ₂₃	91.57	92.09	92.65	93.18	93.67	94.22	95.62	95.12
	X ₂₄	75.18	76.29	78.29	80.28	82.18	88.27	89.27	91.26
	X ₂₅	87.13	87.58	88.06	88.64	88.89	89.05	89.89	90.32
	X ₂₆	94.05	94.75	95.67	95.96	96.16	97.87	97.32	97.28
	X ₃₁	66.19	66.69	68.76	69.28	68.32	70.27	72.08	80.32
Indicators of ecological environmental pollution (X ₃)	X ₃₂	2.1027	2.0527	1.9627	1.8236	1.7528	1.6018	1.5281	1.0827
	X ₃₃	0.5165	0.4792	0.4306	0.3963	0.3625	0.3179	0.2843	0.3026
	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 ecological 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	68.39	69.38	71.29	75.38	78.38	82.38	89.32	91.02
	X ₄₅	75.28	79.37	82.39	85.28	87.38	89.27	90.27	91.67
	X ₄₆	44.84	51.84	78.78	96.47	141.22	156.34	161.22	165.47

2.1.3 Definition of evaluation standard

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 ecological compensation effect of environmental pollution treatment in industrial parks. There are two levels of evaluation standard for the ecological compensation effect of environmental pollution loss in industrial

parks, they are: the indicator level and the result level (Greco et al., 2019). The definition of the evaluation standard is based on various specific laws and regulations that have been promulgated in China, the latest research results at home and abroad were used for reference. The evaluation standard of each specific evaluation index is shown in Table 3.

Table 3 Standard definition of the comprehensive evaluation indicators system of ECEE of energy consumption pollution treatment in Nanjing MV Industrial Park

No.	Indicator's name	Level I	Level II	Level III	Level IV	Level V
1	Per capita gross output value (X_{11})	>17	10-17	8-10	5-8	<5
2	Return on equity (X_{12})	>30	20-30	10-20	5-10	<5
3	Energy consumption intensity (X_{13})	0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	>2
4	Proportion of fiscal investment in EEC (X_{14})	>50	40-50	30-40	20-30	<20
5	Investment intensity of ecological restoration (X_{15})	>500	350-500	200-350	100-200	<100
6	IEPT / total output value (X_{16})	>2.5	2.0-2.5	1.5-2.0	1-1.5	<1
7	Ecological environment index (X_{21})	>200	150-200	100-150	50-100	<50
8	Environmental greening rate (X_{22})	>32	20-32	10-20	5-10	<5
9	Standard rate of ecological compensation (X_{23})	90-100	80-90	70-80	60-70	<60
10	Ecological landscape index (X_{24})	>200	150-200	100-150	50-100	<50
11	Standard rate of resource compensation (X_{25})	90-100	80-90	70-80	60-70	<60
12	Percentage of "Green Certified" Enterprises in the Park (X_{26})	90-100	80-90	70-80	60-70	<60
13	Compensation rate of EPL (X_{31})	95-100	80-95	70-80	60-70	<60
14	EC CO ₂ emission intensity (X_{32})	0-1	1-1.5	1.5-2.0	2-2.5	>2.5
15	IWG emission intensity (X_{33})	0-0.25	0.25-0.5	0.5-0.75	0.75-0.1	>1
16	IWW emission intensity (X_{34})	0-0.5	0.5-1	1-1.5	1.5-2	>2
17	Emission intensity of solid waste (X_{35})	0-50	50-200	200-350	350-500	>500
18	Air pollution index (X_{36})	0-50	50-100	100-200	200-300	>300
19	Water pollution index (X_{37})	0-50	50-100	100-200	200-300	>300
20	Land pollution index (X_{38})	0-50	50-100	100-200	200-300	>300
21	Standard rate of IWW treatment (X_{41})	85-100	75-85	60-75	40-60	<40
22	Standard rate of IWG emission treatment (X_{42})	85-100	75-85	60-75	40-60	<40
23	Comprehensive utilization rate of ISW (X_{43})	85-100	75-85	60-75	40-60	<40
24	Domestic waste treatment rate (X_{44})	90-100	80-90	70-80	50-70	<50
25	Domestic wastewater treatment rate (X_{45})	90-100	80-90	70-80	50-70	<50
26	Comprehensive index of EPT (X_{46})	>200	150-200	100-150	50-100	<50

The evaluation grade standard of the ecological compensation effect of environmental pollution loss is based on the evaluation indicators standard and evaluation results, referring to the latest research results at home and abroad, combining with the development planning and actual situation of China's industrial parks, taking the specific comprehensive evaluation coefficient of the ecological compensation effect of environmental pollution loss as the grading standard, and the ecological compensation effect of environmental pollution loss are subdivided into five levels: excellent [0.9, 1], good [0.8, 0.9), medium [0.7, 0.8), qualified [0.6, 0.7), unqualified [0, 0.6). According to the requirements of national environmental pollution treatment, the industrial park has raised the grade standard of ecological compensation for environmental pollution loss, and implemented a one-vote veto system for ecological compensation failures.

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 spatial and temporal position of a population in the ecosystem and its function and relationship with related populations, and it represents the minimum habitat necessary for the survival of each organism in the ecosystem (Godsoe et al., 2017). Niche modeling (NM) refers to a mathematical model that uses the niche theory and method to determine the level of ecological compensation effect by calculating the niche suitability of evaluation indicators (Julián et al., 2019). The quantitative indicators of each ecological factor are defined as follows: $x_1(t), x_2(t), \dots, x_n(t), x_i(t) \in I_i$, I_i is the variation range of the i th ecological factor that can be expressed as: $I_i = [a_i, b_i]$, ($i = 1, 2, \dots, n$). Then, the range of ecological factor can be expressed as: $E = I_1 \times I_2 \times \dots \times I_n = \prod_{i=1}^n I_i$. E is a subset of N-dimensional ecological factor E^n , if the niche function is a non-negative N-dimensional function: $f(X_i) = f(x_1(t), x_2(t), \dots, x_n(t))$, then niche N of this population

216 can be expressed as:

$$217 \quad N = \{X_t | f(X_t) > 0, X_t = (x_1(t), x_2(t), \dots, x_n(t))\}, \quad N \cap E \neq \Phi \quad (1)$$

218 According to the theory of ecology, niche suitability interval is (0, 1). The greater the value, the higher
219 the degree to which ecological factors meet ecological needs (Basille et al., 2008). The optimum value of
220 ecological factors is denoted as: $X_\alpha = (x_1(\alpha), x_2(\alpha), \dots, x_n(\alpha))$, $X_t \in E$, then; the niche suitability of
221 ecological factors is denoted as:

$$222 \quad F = \phi(X_\alpha, X_t), \quad X_\alpha \in N, \quad X_t \in E \quad (2)$$

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

227 2.2.2 Average operator model (F_t)

228 If the suitability of ecological factors in the industrial park in the time period t is expressed as F_t , then
229 the corresponding average operator niche suitability model is expressed as:

$$230 \quad F_t = \frac{1}{n} \sum_{i=1}^n \frac{\delta_{\min} + \alpha \times \delta_{\max}}{\delta_{it} + \alpha \times \delta_{\max}} = \frac{1}{n} \sum_{i=1}^n \frac{\min\{|x'_i(t) - x'_i(\alpha)|\} + \alpha \times \max\{|x'_i(t) - x'_i(\alpha)|\}}{|x'_i(t) - x'_i(\alpha)| + \alpha \times \max\{|x'_i(t) - x'_i(\alpha)|\}} \quad (3)$$

231 In the formula: $\delta_{it} = |x'_i(t) - x'_i(\alpha)|$, ($i = 1, 2, \dots, n$; $t = 1, 2, \dots, m$)

$$232 \quad \delta_{\max} = \max\{\delta_{it}\} = \max\{|x'_i(t) - x'_i(\alpha)|\}$$

$$233 \quad \delta_{\min} = \min\{\delta_{it}\} = \min\{|x'_i(t) - x'_i(\alpha)|\}$$

234 α is the model parameter, and the value range of α is: ($0 \leq \alpha \leq 1$). The calculation results of the
235 model can be adjusted by taking the value of the model parameters according to the changes of
236 environmental conditions. Under normal circumstances, $x_t(\alpha)$ take the maximum value in each
237 evaluation result.

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 so that it is called the limiting factor model. The specific formula is:

$$F_{\min-t} = \min\{(x'_1(t)/x'_1(\alpha)), (x'_2(t)/x'_2(\alpha)), \dots, (x'_n(t)/x'_n(\alpha))\} \quad (4)$$

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

2.3 Construction of comprehensive evaluation model of niche suitability

According to niche theory and method, the evaluation indicators are expressed as follows: $x_1, x_2, \dots, x_n$. Considering the time series of each evaluation indicator, the observed values constitute the ecological matrix of $m \times n$ dimension: $(i = 1, 2, \dots, m; t = 1, 2, \dots, n)$. In order to build a comprehensive evaluation model of spatial niche suitability for ecological compensation effect, the generalized relational grade of gray theory is introduced to calculate the niche of ecological factors (Yang, 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 suitability model is represented by $\varepsilon_{t\alpha}$ and the relative niche suitability model is represented by $\gamma_{t\alpha}$. 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, et al., 2019). The first-order buffer operator of the actual value of ecological factors can be expressed as:

$$X_{it}d_t = \left(\left(\sum_{t=1}^n x_{it} \right) \cdot d_1, \left(\sum_{t=2}^n x_{it} \right) \cdot d_2, \dots, \left(\sum_{t=n}^n x_{it} \right) \cdot d_n \right), (i=1,2,\dots,m; t=1,2,\dots,n) \quad (5)$$

In the formula $d_t = 1/(n - t + 1)$, 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:

$$X_{it}d^2 = (X_{it}d_t) \cdot d_t = \left(\left(\sum_{t=1}^n X_{it}d_t \right) \cdot d_1, \left(\sum_{t=2}^n X_{it}d_t \right) \cdot d_2, \dots, \left(\sum_{t=n}^n X_{it}d_t \right) \cdot d_n \right) \quad (6)$$

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

$$\begin{cases} X'_{it} = (X_{it}d^2) / ((\max X_{ik})) & (\text{forward pointer}) \\ X'_{it} = 1 - (X_{it}d^2) / ((\max X_{ik})) & (\text{contrary indicator}) \end{cases} \quad (7)$$

In the above equation $i=1,2,\dots,m; t=1,2,\dots,n; k=1,2,\dots,5$: k is the grading symbol in Table 3. x'_{it} represents the dimensionless value of the i_{th} evaluation factor in the t year; x_{it} represents the original value of i_{th} evaluation indicator in the t year; $\max X_{ik}$ represents i_{th} evaluation factor and the maximum value of k, when the evaluation indicator is a positive indicator, the level is the maximum value. When the evaluation indicator is a contrary indicator, the level is the maximum value. When the maximum value tends to infinity, the lower boundary value of the maximum interval is taken. When the positive indicator is larger than the lower boundary, the value range is 1, and when the contrary indicator is larger than the lower boundary, the value range is zero. If the optimal suitability of the evaluation indicators is $x'_{i\alpha}$, there are:

$$X'_{i\alpha} = \max (X'_{it}) \quad (8)$$

On the basis of dimensionless processing, the null transformation is carried out according to the results of dimensionless processing. The absolute null transformation uses the following formula:

$$\begin{cases} X'_{it}(0) = (X'_{1t}(0), X'_{2t}(0), \dots, X'_{mt}(0)) = X_{it} - X_{1t} \\ X'_{i\alpha}(0) = (X'_{1\alpha}(0), X'_{2\alpha}(0), \dots, X'_{m\alpha}(0)) = X_{i\alpha} - X_{1\alpha} \end{cases} \quad (9)$$

The comprehensive evaluation model of spatial niche suitability is the weighted average of the absolute niche suitability model and relative niche suitability model. In the actual construction of the evaluation model, the method and application of determining absolute and relative niche suitability model can be studied according to the specific requirements of the comprehensive evaluation. In order to construct a comprehensive evaluation model of spatial niche suitability, the absolute niche suitability measurement model is first constructed. The specific model expression is as follows:

$$\mathcal{E}_{i\alpha} = \frac{1 + |S_{\alpha}| + |S_t|}{1 + |S_{\alpha}| + |S_t| + |S_{\alpha} - S_t|} \quad (10)$$

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

Then, using the processing data after the second-order weakening buffer zone and the results of dimensionless processing, the relative niche suitability measurement model is constructed. The calculation formula of the relative null transformation for evaluation indicators is as follows:

$$\begin{cases} X'_{it}(0) = (X'_{1t}(0), X'_{2t}(0), \dots, X'_{mt}(0)) = (X_{it} / X_{1t}) - 1 \\ X'_{i\alpha}(0) = (X'_{1\alpha}(0), X'_{2\alpha}(0), \dots, X'_{m\alpha}(0)) = (X_{i\alpha} / X_{1\alpha}) - 1 \end{cases} \quad (11)$$

In order to construct a comprehensive evaluation model of spatial niche suitability, a relative niche suitability measurement model needs to be constructed. The specific model of relative niche is as follows:

$$\mathcal{V}_{i\alpha} = \frac{1 + |S'_{\alpha}| + |S'_t|}{1 + |S'_{\alpha}| + |S'_t| + |S'_{\alpha} - S'_t|} \quad (12)$$

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

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In the above formula, if $F_{t\alpha}$ is used to represent the comprehensive evaluation model of spatial niche

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suitability, there are:

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$$F_{t\alpha} = \theta \varepsilon_{t\alpha} + (1 - \theta) \gamma_{t\alpha} \quad (13)$$

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Where, $\theta (0 \leq \theta \leq 1)$ is the weighting coefficient, and considering that the importance of the

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absolute niche suitability and the relative niche suitability are the same, the value of θ is taken as 0.5.

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When the value of θ is less than 0.5 and tends to 0, the value of spatial niche suitability tends to relative

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niche suitability. When the value of θ is greater than 0.5 and tends to 1, the value of spatial niche

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suitability tends to absolute niche suitability.

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3. Result

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3.1 Second-order buffer calculation of evaluation indicators

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The purpose of buffer calculation is to improve the stability of the evaluation indicators. For the basic data

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in Table 1, the second-order buffer correction formulas (5) and (6) of evaluation indicators were used for buffer

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calculation to eliminate the large fluctuation in the original data, which can make the data more stable and

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improve the effectiveness of the comprehensive evaluation results of the ecological compensation for

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environmental pollution loss in Nanjing MV Industrial Park. According to the above research design, the

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second-order buffer calculation is carried out for the comprehensive evaluation indicators by using the buffer

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calculation model, and the specific buffer calculation results are shown in Table 4.

Table 4 The second-order buffer treatment results of indicators of ECEE for environmental pollution treatment of Nanjing MV Industrial Park

Indicators	2011	2012	2013	2014	2015	2016	2017	2018
X ₁₁	14.1287	14.3646	14.6287	14.9247	15.2556	15.6108	15.9867	16.3217
X ₁₂	25.0141	25.3340	25.6913	26.1279	26.7254	27.4439	27.8475	28.3700
X ₁₃	0.6181	0.6026	0.5865	0.5705	0.5557	0.5388	0.5192	0.4981
X ₁₄	48.0911	48.1525	48.2110	48.2648	48.3010	48.2989	48.1850	48.0600
X ₁₅	434.0152	437.1245	440.3833	443.3933	446.0417	447.5556	449.0000	450.0000
X ₁₆	1.8581	1.8733	1.8893	1.9076	1.9292	1.9512	1.9835	2.0137
X ₂₁	159.5095	162.8284	166.1845	169.4181	172.3656	175.1550	177.0975	176.6700
X ₂₂	27.6976	27.9350	28.1977	28.4963	28.8533	29.2911	29.7900	30.2800
X ₂₃	94.4851	94.6237	94.7621	94.8992	95.0335	95.1589	95.2450	95.1200
X ₂₄	87.0457	87.6769	88.3412	89.0244	89.7175	90.3750	90.7625	91.2600
X ₂₅	89.4786	89.5906	89.7026	89.8148	89.9290	90.0594	90.2125	90.3200
X ₂₆	96.9273	97.0408	97.1426	97.2291	97.3069	97.3567	97.2900	97.2800
X ₃₁	73.5132	73.9810	74.5083	75.1090	75.8727	76.9144	78.2600	80.3200
X ₃₂	1.4864	1.4504	1.4111	1.3683	1.3209	1.2641	1.1941	1.0827
X ₃₃	0.3313	0.3234	0.3160	0.3094	0.3036	0.2992	0.2980	0.3026
X ₃₄	0.7768	0.7462	0.7124	0.6739	0.6305	0.5814	0.5325	0.4825
X ₃₅	104.6237	96.2403	87.9184	79.6704	71.3585	63.4056	56.7250	49.5400
X ₃₆	82.6737	77.1330	71.9342	67.1210	62.6198	58.0472	54.0775	50.3200
X ₃₇	54.1511	52.2155	50.6510	49.6832	49.1215	48.8061	48.5625	48.3200
X ₃₈	102.5376	95.2756	87.9871	80.5291	72.9929	66.0639	61.2875	58.2900
X ₄₁	78.7649	79.4458	80.1698	80.9591	81.8454	82.9039	84.3075	86.2800
X ₄₂	78.7736	79.0515	79.2660	79.4502	79.6238	79.8800	80.1300	80.3800
X ₄₃	81.1058	81.6000	82.0717	82.5227	82.9494	83.3667	83.8150	84.2900
X ₄₄	84.5518	85.4603	86.4382	87.4669	88.5096	89.5878	90.5950	91.0200
X ₄₅	88.8509	89.3848	89.8625	90.2930	90.6727	91.0144	91.3200	91.6700
X ₄₆	144.6155	149.2716	153.8803	158.0063	161.4719	163.2750	164.4075	165.4700

3.2 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 comprehensive evaluation indicators by selecting appropriate variables instead. The most commonly used dimensionless treatment is normalization, to merge all the values of the evaluation indicators into $[0, 1]$ by specific methods. For the difference between the positive pointers and the contrary indicators, the merging principle of the positive pointers is the maximum of 1 and the minimum of 0; the merging principle of the contrary indicators is the opposite of the positive pointers, the minimum of 1 and the maximum of 0. In the dimensionless process 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 the ECEE indicators of energy consumption pollution treatment in Nanjing MV Industrial Park

Indicators	2011	2012	2013	2014	2015	2016	2017	2018	x'_{ia}
X ₁₁	0.8311	0.8450	0.8605	0.8779	0.8974	0.9183	0.9404	0.9601	0.8311
X ₁₂	0.8338	0.8445	0.8564	0.8709	0.8908	0.9148	0.9283	0.9457	0.8338
X ₁₃	0.6909	0.6987	0.7067	0.7148	0.7222	0.7306	0.7404	0.7510	0.6909
X ₁₄	0.9618	0.9630	0.9642	0.9653	0.9660	0.9660	0.9637	0.9612	0.9618
X ₁₅	0.8680	0.8742	0.8808	0.8868	0.8921	0.8951	0.8980	0.9000	0.8680
X ₁₆	0.7432	0.7493	0.7557	0.7630	0.7717	0.7805	0.7934	0.8055	0.7432
X ₂₁	0.7975	0.8141	0.8309	0.8471	0.8618	0.8758	0.8855	0.8834	0.7975
X ₂₂	0.8656	0.8730	0.8812	0.8905	0.9017	0.9153	0.9309	0.9463	0.8656
X ₂₃	0.9449	0.9462	0.9476	0.9490	0.9503	0.9516	0.9525	0.9512	0.9449
X ₂₄	0.4352	0.4384	0.4417	0.4451	0.4486	0.4519	0.4538	0.4563	0.4352
X ₂₅	0.8948	0.8959	0.8970	0.8981	0.8993	0.9006	0.9021	0.9032	0.8948
X ₂₆	0.9693	0.9704	0.9714	0.9723	0.9731	0.9736	0.9729	0.9728	0.9693
X ₃₁	0.7351	0.7398	0.7451	0.7511	0.7587	0.7691	0.7826	0.8032	0.7351
X ₃₂	0.4054	0.4198	0.4356	0.4527	0.4716	0.4944	0.5224	0.5669	0.4054
X ₃₃	0.6687	0.6766	0.6840	0.6906	0.6964	0.7008	0.7020	0.6974	0.6687
X ₃₄	0.6116	0.6269	0.6438	0.6631	0.6848	0.7093	0.7337	0.7588	0.6116
X ₃₅	0.7908	0.8075	0.8242	0.8407	0.8573	0.8732	0.8866	0.9009	0.7908
X ₃₆	0.7244	0.7429	0.7602	0.7763	0.7913	0.8065	0.8197	0.8323	0.7244
X ₃₇	0.8195	0.8259	0.8312	0.8344	0.8363	0.8373	0.8381	0.8389	0.8195
X ₃₈	0.6582	0.6824	0.7067	0.7316	0.7567	0.7798	0.7957	0.8057	0.6582
X ₄₁	0.7876	0.7945	0.8017	0.8096	0.8185	0.8290	0.8431	0.8628	0.7876
X ₄₂	0.7877	0.7905	0.7927	0.7945	0.7962	0.7988	0.8013	0.8038	0.7877
X ₄₃	0.8111	0.8160	0.8207	0.8252	0.8295	0.8337	0.8382	0.8429	0.8111
X ₄₄	0.8455	0.8546	0.8644	0.8747	0.8851	0.8959	0.9060	0.9102	0.8455
X ₄₅	0.8885	0.8938	0.8986	0.9029	0.9067	0.9101	0.9132	0.9167	0.8885
X ₄₆	0.7231	0.7464	0.7694	0.7900	0.8074	0.8164	0.8220	0.8274	0.7231

In order to improve the evaluation effect, the dimensionless maximum value is selected according to the maximum value in Table 3. The lower boundary value is selected when the maximum value tends to infinity; the value range of the positive pointer greater than such standard is 1, and the value range of the contrary indicator greater than such standard is 0.

3.3 Null transformation of evaluation indicators

(1) Absolute null transformation calculation. Absolute null transformation processing refers to the use of the difference method to determine the zero base of the first row, that is, the data of each row of all evaluation indicators minus the base data of the first row, so that the difference of the first row is zero, and the calculation of correlation coefficient is started from zero, and the method of generalized relational grade of gray theory is used to calculate the correlation degree of the evaluation indicators to the evaluation objects. The specific calculation results are shown in Table 6.

Table 6 The results of absolute null transformation for the ECEE indicators of energy consumption pollution treatment in Nanjing MV Industrial Park

Indicators	2011	2012	2013	2014	2015	2016	2017	2018	$x'_{ia}(0)$
X ₁₁	0	0	0	0	0	0	0	0	0
X ₁₂	0.0027	-0.0005	-0.0041	-0.0070	-0.0065	-0.0035	-0.0121	-0.0144	-0.0144
X ₁₃	-0.1401	-0.1463	-0.1538	-0.1632	-0.1752	-0.1877	-0.2000	-0.2092	-0.2092
X ₁₄	0.1307	0.1181	0.1037	0.0874	0.0686	0.0477	0.0233	0.0011	0.0059
X ₁₅	0.0369	0.0293	0.0203	0.0089	-0.0053	-0.0232	-0.0424	-0.0601	-0.0601
X ₁₆	-0.0879	-0.0957	-0.1048	-0.1149	-0.1257	-0.1378	-0.1470	-0.1546	-0.1546
X ₂₁	-0.0335	-0.0308	-0.0296	-0.0308	-0.0356	-0.0425	-0.0549	-0.0768	-0.0746
X ₂₂	0.0345	0.0280	0.0207	0.0126	0.0043	-0.0029	-0.0095	-0.0138	-0.0138
X ₂₃	0.1138	0.1013	0.0871	0.0711	0.0529	0.0333	0.0121	-0.0089	-0.0076
X ₂₄	-0.3959	-0.4066	-0.4188	-0.4328	-0.4488	-0.4664	-0.4866	-0.5038	-0.5038
X ₂₅	0.0637	0.0509	0.0365	0.0202	0.0019	-0.0177	-0.0383	-0.0569	-0.0569
X ₃₁	0.1382	0.1254	0.1109	0.0944	0.0757	0.0553	0.0325	0.0127	0.0135
X ₃₂	-0.0960	-0.1052	-0.1154	-0.1268	-0.1387	-0.1491	-0.1578	-0.1569	-0.1569
X ₃₃	-0.4257	-0.4252	-0.4250	-0.4252	-0.4258	-0.4239	-0.4180	-0.3932	-0.3932
X ₃₄	-0.1624	-0.1684	-0.1765	-0.1874	-0.2010	-0.2175	-0.2384	-0.2627	-0.2581
X ₃₅	-0.2195	-0.2181	-0.2167	-0.2149	-0.2126	-0.2090	-0.2067	-0.2014	-0.2014
X ₄₁	-0.0403	-0.0375	-0.0363	-0.0373	-0.0401	-0.0451	-0.0538	-0.0592	-0.0592
X ₄₂	-0.1067	-0.1021	-0.1003	-0.1017	-0.1061	-0.1118	-0.1207	-0.1278	-0.1278
X ₄₃	-0.0116	-0.0190	-0.0293	-0.0435	-0.0611	-0.0810	-0.1023	-0.1212	-0.1212
X ₄₄	-0.1729	-0.1626	-0.1538	-0.1464	-0.1407	-0.1385	-0.1447	-0.1544	-0.1544
X ₅₁	-0.0434	-0.0505	-0.0588	-0.0683	-0.0789	-0.0892	-0.0973	-0.0973	-0.0973
X ₅₂	-0.0434	-0.0545	-0.0679	-0.0834	-0.1011	-0.1195	-0.1391	-0.1563	-0.1563
X ₅₃	-0.0200	-0.0290	-0.0398	-0.0527	-0.0679	-0.0846	-0.1022	-0.1172	-0.1172
X ₅₄	0.0144	0.0096	0.0039	-0.0033	-0.0123	-0.0224	-0.0344	-0.0499	-0.0499
X ₅₅	0.0574	0.0489	0.0381	0.0250	0.0093	-0.0081	-0.0272	-0.0434	-0.0434
X ₅₆	-0.1080	-0.0986	-0.0911	-0.0879	-0.0900	-0.1019	-0.1184	-0.1328	-0.1328

(2) Relative null transformation calculation. Relative null transformation processing refers to the use of the ratio method to determine the zero base of the first row, that is, the ratio of the data in each row of

all evaluation indicators to the first row is used, and the ratio minus 1 is used as the calculation result; the data in the first row is zero. The specific calculation results are shown in Table 7.

Table 7 The results of relative null transformation for the ECEE indicators of energy consumption pollution treatment in Nanjing MV Industrial Park

Indicators	2011	2012	2013	2014	2015	2016	2017	2018	$x_{in}^r(0)$
X ₁₁	0	0	0	0	0	0	0	0	0
X ₁₂	0.0033	-0.0006	-0.0048	-0.0080	-0.0073	-0.0038	-0.0129	-0.0150	-0.0150
X ₁₃	-0.1686	-0.1731	-0.1787	-0.1858	-0.1953	-0.2044	-0.2127	-0.2178	-0.2178
X ₁₄	0.1573	0.1397	0.1205	0.0995	0.0765	0.0519	0.0248	0.0011	0.0062
X ₁₅	0.0444	0.0346	0.0235	0.0101	-0.0059	-0.0252	-0.0451	-0.0626	-0.0626
X ₁₆	-0.1057	-0.1132	-0.1218	-0.1309	-0.1401	-0.1501	-0.1563	-0.1610	-0.1610
X ₂₁	-0.0404	-0.0365	-0.0344	-0.0351	-0.0396	-0.0463	-0.0584	-0.0799	-0.0777
X ₂₂	0.0415	0.0331	0.0240	0.0143	0.0048	-0.0032	-0.0101	-0.0144	-0.0144
X ₂₃	0.1369	0.1198	0.1012	0.0809	0.0590	0.0363	0.0128	-0.0093	-0.0080
X ₂₄	-0.4763	-0.4812	-0.4867	-0.4930	-0.5001	-0.5079	-0.5174	-0.5247	-0.5247
X ₂₅	0.0766	0.0603	0.0424	0.0230	0.0021	-0.0193	-0.0407	-0.0593	-0.0593
X ₃₁	0.1663	0.1484	0.1289	0.1075	0.0843	0.0602	0.0346	0.0132	0.0140
X ₃₂	-0.1155	-0.1245	-0.1341	-0.1445	-0.1545	-0.1624	-0.1678	-0.1634	-0.1634
X ₃₃	-0.5122	-0.5032	-0.4938	-0.4844	-0.4744	-0.4616	-0.4445	-0.4095	-0.4095
X ₃₄	-0.1954	-0.1993	-0.2052	-0.2134	-0.2240	-0.2369	-0.2535	-0.2736	-0.2689
X ₃₅	-0.2641	-0.2581	-0.2518	-0.2447	-0.2369	-0.2276	-0.2198	-0.2097	-0.2097
X ₄₁	-0.0485	-0.0443	-0.0422	-0.0424	-0.0447	-0.0491	-0.0573	-0.0616	-0.0616
X ₄₂	-0.1284	-0.1208	-0.1165	-0.1158	-0.1183	-0.1217	-0.1283	-0.1331	-0.1331
X ₄₃	-0.0140	-0.0225	-0.0341	-0.0496	-0.0681	-0.0882	-0.1087	-0.1262	-0.1262
X ₄₄	-0.2080	-0.1924	-0.1787	-0.1667	-0.1568	-0.1508	-0.1539	-0.1608	-0.1608
X ₅₁	-0.0523	-0.0598	-0.0683	-0.0778	-0.0880	-0.0972	-0.1035	-0.1013	-0.1013
X ₅₂	-0.0522	-0.0645	-0.0788	-0.0950	-0.1127	-0.1301	-0.1479	-0.1628	-0.1628
X ₅₃	-0.0241	-0.0343	-0.0462	-0.0600	-0.0757	-0.0921	-0.1087	-0.1221	-0.1221
X ₅₄	0.0174	0.0114	0.0045	-0.0037	-0.0137	-0.0244	-0.0366	-0.0520	-0.0520
X ₅₅	0.0691	0.0578	0.0443	0.0285	0.0104	-0.0089	-0.0289	-0.0452	-0.0452
X ₅₆	-0.1300	-0.1167	-0.1059	-0.1001	-0.1003	-0.1110	-0.1259	-0.1383	-0.1383

3.4 Evaluation results of ecological compensation effect of environmental pollution loss

The comprehensive evaluation of the ecological compensation effect of environmental pollution loss in Nanjing MV Industrial Park is divided into two layers: criterion layer and target layer. According to the above research design, the following is the application analysis for the two layers of comprehensive evaluation of ecological compensation effect of environmental pollution loss:

(1) Comprehensive evaluation result of target layer indicators. According to the principle of the niche model, the selected 26 evaluation indicators were comprehensively evaluated to determine the comprehensive evaluation results of the ecological compensation effect of environmental pollution treatment in Nanjing MV Industrial Park. See Table 8 for details.

Table 8 The results of ECEE of environmental pollution treatment of Nanjing MV Industrial Park for the target layer indicators

Evaluation method	Indicators	2011	2012	2013	2014	2015	2016	2017	2018
$\mathcal{E}_{t\alpha}$	$ S_i $	0.4483	0.6205	0.8437	1.1242	1.4613	1.8311	2.2675	2.6181
	$ S_\alpha - S_i $	1.4417	1.3320	1.1874	1.0025	0.7773	0.5254	0.2268	0.0136
	$1+ S_\alpha + S_i $	3.4461	3.7183	4.4414	4.7220	5.0590	5.4288	5.8652	6.1358
	$1+ S_\alpha + S_i + S_\alpha-S_i $	4.8878	5.0503	5.7689	5.8645	5.8863	5.9862	6.2320	6.2694
	Evaluation results	0.7050	0.7363	0.7699	0.8052	0.8595	0.9069	0.9411	0.9787
	Level	III	III	III	II	II	I	I	I
$\gamma_{t\alpha}$	$ S_i $	2.5977	0.5712	0.7776	1.0381	1.3559	1.7242	2.1113	2.5530
	$ S'_\alpha - S'_i $	1.5335	1.4029	1.2350	1.0262	0.7806	0.5168	0.2145	0.0149
	$1+ S'_\alpha + S'_i $	4.6360	4.6424	4.9030	5.2208	5.5890	5.9762	6.1879	6.7521
	$1+ S'_\alpha + S'_i + S'_\alpha-S'_i $	6.0196	5.8697	6.0178	6.1669	6.2696	6.3893	6.4023	6.7671
	Evaluation results	0.7702	0.7909	0.8147	0.8466	0.8914	0.9353	0.9665	0.9978
	Level	III	III	II	II	II	I	I	I
$F_{t\alpha}$	$\mathcal{E}_{t\alpha}$	0.7050	0.7363	0.7699	0.8052	0.8595	0.9069	0.9411	0.9787
	$\gamma_{t\alpha}$	0.7702	0.7909	0.8147	0.8466	0.8914	0.9353	0.9665	0.9978
	θ	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Evaluation results	0.7376	0.7636	0.7923	0.8259	0.8755	0.9211	0.9538	0.9883
	Level	III	III	III	II	II	I	I	I

(2) Comprehensive evaluation result of criterion layer indicators. If the criterion layer indicators are used as the evaluation objects, the basic data of the measures layer indicators contained in each indicator of the criterion layer and formulas (9) ~ (12) can be used to comprehensively evaluate the criterion layer indicators. The evaluation results of the three methods are shown in Table 9.

Table 9 The results of ECEE of environmental pollution treatment of Nanjing MV Industrial Park for the criterion layer indicators

Evaluation method	Indicators	2011	2012	2013	2014	2015	2016	2017	2018
$\mathcal{E}_{t\alpha}$	X ₁	0.7052	0.7365	0.7701	0.8054	0.8597	0.9071	0.9413	0.9789
	X ₂	0.7105	0.7420	0.7759	0.8114	0.8662	0.9139	0.9484	0.9863
	X ₃	0.6725	0.7076	0.7399	0.7738	0.8260	0.8716	0.9044	0.9406
	X ₄	0.6820	0.7227	0.7557	0.7903	0.8436	0.8901	0.9237	0.9606
$\gamma_{t\alpha}$	X ₁	0.7612	0.7829	0.8052	0.8364	0.8861	0.9278	0.9627	0.9957
	X ₂	0.7726	0.7932	0.8206	0.8466	0.8975	0.9386	0.9703	0.9968
	X ₃	0.7243	0.7436	0.7883	0.8167	0.8467	0.8977	0.9181	0.9565
	X ₄	0.7747	0.7946	0.8207	0.8508	0.9016	0.9438	0.9974	0.9986
$F_{t\alpha}$	X ₁	0.7332	0.7597	0.7877	0.8209	0.8729	0.9175	0.9520	0.9873
	X ₂	0.7416	0.7676	0.7983	0.8290	0.8819	0.9263	0.9594	0.9916
	X ₃	0.6984	0.7256	0.7641	0.7953	0.8364	0.8847	0.9113	0.9486
	X ₄	0.7284	0.7587	0.7882	0.8206	0.8726	0.9170	0.9605	0.9796

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4. Discussion

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4.1 Evaluation grade change rule and problems found

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In order to analyze the laws and problems of the evaluation results, effective improvement strategies are formulated according to the analysis results. In the rectangular coordinate system, draw the change rule diagram of the evaluation result of the ecological compensation effect of the environmental pollution loss at the criterion layer. The specific change rule and the interrelation are shown in Figure 1.

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Fig.1. Change rule and interrelation diagram of the results of ECEE of environmental pollution loss in Nanjing MV Industrial Park

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According to the evaluation results of the ecological compensation effect of environmental pollution

loss in Nanjing MV Industrial Park for criteria layer, the evaluation result of the ecological compensation effect for the economic effect indicators in 2011 was 0.7332 (level III), which was a medium level. By 2018, the evaluation result of the ecological compensation effect was increased to 0.9873 (level I), which was the excellent level; the evaluation result of the ecological compensation effect for the ecological compensation indicators in 2011 is 0.7416 (Level III), which was the medium level. By 2018, it increased to 0.9916 (Level I), which was the excellent level; the evaluation result of the ecological compensation effect for the ecological environmental pollution indicators in 2011 was 0.6984 (Level IV), which was the qualified level. By 2018, it increased to 0.9484 (level I), which was the excellent level; the evaluation result of the ecological compensation effect for the ecological environmental pollution treatment indicators in 2011 was 0.7284 (Level III), which was the medium level. By 2018, it increased to 0.9796 (level I), which was the excellent level.

From the above evaluation results, it can be seen that the ecological compensation effect of environmental pollution in Nanjing MV Industrial Park is good, indicating that the economic development of the industrial park is good, and more attention is paid to environmental pollution treatment. However, the status of ecological compensation and environmental pollution in the industrial park is still not ideal, in particular, the evaluation results in 2011-2013 were level III, the evaluation results for 2014-2015 were level II, and although they were level I for 2016-2018, the evaluation results of the first two years were obviously low. Improving the effectiveness of environmental pollution treatment is still the main issue faced by Nanjing MV Industrial Park, which needs to be further strengthened.

4.2 The implementation effect of ecological compensation system and the problems found

Nanjing MV Industrial Park has implemented a comprehensive ecological compensation system for environmental pollution losses since 2018. According to the collected data, the influencing factor diagram

of the evaluation indicators is shown in Figure 2.

Fig.2 The change trend chart of the influencing factors of the ecological compensation effect of the environmental pollution loss in Nanjing MV Industrial Park

The change range and trend of the evaluation indicators above affect and determine the evaluation results of the ecological compensation effect of environmental pollution treatment in industrial parks. In order to analyze the implementation effect of the ecological compensation 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 ecological compensation effect is significantly improved. See figure 3 for the specific change trend and interrelation.

Fig.3 Change trend and interrelation chart of evaluation results of different evaluation models

From the comparative analysis of the evaluation results of the environmental pollution ecological compensation effect of Nanjing MV Industrial Park in 2018 and the previous year's evaluation results, it can be seen that the ecological compensation effect in 2018 is significantly improved compared with any year before 2018, indicating that the ecological compensation effect of the environmental pollution loss in Nanjing MV Industrial Park has had an obvious effect since 2018. Although it can't be said that these obvious effects are all brought by the implementation of the ecological compensation scheme, it is certain that there will be effects brought by the implementation of the ecological compensation scheme. The ecological compensation 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 ecological compensation scheme for environmental pollution loss. With the continuous implementation of the ecological compensation scheme for environmental pollution loss in Nanjing MV Industrial Park, its ecological compensation effect will gradually appear. The research of ecological compensation scheme for environmental pollution loss in Nanjing MV Industrial Park still needs to be deepened. Only through continuous research and exploration, the Nanjing MV Industrial Park can gradually improve the ecological compensation system and promote the gradual formation of the "U" turning trend of environmental pollution.

5. Conclusions

In order to solve the comprehensive evaluation problem of the ecological compensation effects for environmental pollution losses in Nanjing MV Industrial Park, this paper proposed a spatial niche suitability model. Based on literature review, theoretical analysis, questionnaire survey, and expert evaluation; referred to the latest research results at home and abroad; taken into account the actual situation and requirements of the comprehensive evaluation of the ecological compensation effect for environmental

pollution losses in the industrial park; improved and innovated based on the traditional niche suitability model, this paper constructed a spatial suitability model to provide comprehensive evaluation and application research on ecological compensation effect for environmental pollution losses in the Nanjing Industrial Park. The conclusions are as follows:

First, the overall trend of ecological compensation effect for environmental pollution losses in Nanjing MV Industrial Park is rising, but the effect at the criterion layer is uneven. Therefore, the management authorities of the industrial park should pay special attention to the imbalance of ecological compensation for environmental pollution losses in different areas or enterprises in the park and narrow the gap of ecological compensation effects and management effects by adjusting investment and strengthening management.

Secondly, after the implementation of the ecological compensation system for environmental pollution losses in Nanjing Industrial Park, the effect of ecological compensation has been significantly improved, which can show that the ecological compensation for environmental pollution losses in industrial parks has achieved some results. In order to ensure the continuous improvement of the effect of ecological compensation, it is necessary for the management authorities of the industrial park to continue to implement the ecological compensation system and strengthen the investment in ecological protection and environmental pollution treatment.

Finally, comparing the evaluation results of the spatial niche suitability model with the evaluation results of the absolute and relative niche model, the evaluation results of the spatial niche model are relatively stable. Therefore, it is necessary for the management authorities of the industrial park to pay more attention to the research on the evaluation methods of ecological compensation in environmental pollution treatment for promoting the continuous improvement of the effectiveness of ecological

compensation evaluation.

Availability of data and materials

Not applicable.

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Figures

Figure 1

Change rule and interrelation diagram of the results of ECEE of environmental pollution loss in Nanjing MV Industrial Park

Figure 2

The change trend chart of the influencing factors of the ecological compensation effect of the environmental pollution loss in Nanjing MV Industrial Park

Figure 3

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