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Research Article

Coupling Coordination Degree of City-Industry Integration in Shanghai Based on Entropy Evaluation Method

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With the quality of urbanization getting more attention, city-industry integration has increasingly become a hot topic in academia. This paper is based on the traditional quantitative research of city integration, introducing the measuring model of ternary coupling coordination degree of city-industry integration in Shanghai and highlighting the ecological environment has become an important factor in the process of integration. Through the entropy method and coupling coordination model to measure the integration of Shanghai, a reasonable conclusion was reached within data analyses.

1. Literature Review

In the process of urban development, uncoordinated industrialization and urbanization appear frequently. The degree of fusion between industrial development and urban function is of great significance to the sustainability of a city. Therefore, it is necessary to measure the integration degree between the city and industry. Researchers in academia have measured the integration from different aspects and through different research methods. Zhang [1], in 2004–2018, used F city's statistics as the research object and constructed the evaluation system, including urban development, industry support, and population development as three dimensions of the 18 index. With the objective entropy method to calculate the weight of 18 evaluation indicators, he established the ternary coupling model of F city (production, city, and human). As a result, the city integration coupling degree and coupling coordination degree was evaluated. Shi [2], starting from the perspective of industrial economic development, urban construction, and ecological level, then, the dynamic coupling index system of ecological integration was constructed. With 13 typical resource-based cities as the research objects, the coupling coordination degree model was used to study the coupling relationship among the three. The consequences showed that the ecological coupling of the resource-based city is well coupled and primary coordinated, far from high-quality coupling. There was also an inseparable relationship between industrial economy, urban construction, and resource endowment. There was a positive correlation between industrial economy and ecological development level, while a negative between industrial economy and urbanization level. Finally, the paper put forward feasible countermeasures with the ecological construction from the industry, city, and human development. Zou [3], selected 15 indicators to measure the degree of city-industry integration, using 31 provinces as research objects and based on the relative data from 2000 to 2015. Through the entropy evaluation method, the coupling coordination, and GIS, the differences of space-time structure were conducted and analyzed. He also explored the impact indicators on the coordinated development based on panel data and classification data of city-industry coordination types. Wang [4], focused on urbanization and industrial cluster in Shandong Province and explored a feasible way to build an integrated system. By constructing the coupling model of an urbanization-industrial cluster, the coupling coordination index of 17 cities in Shandong Province was calculated, and the coupling development degree of city-industry coupling in Shandong Province was scientifically evaluated. According to the empirical results, the author came up with suggestions. Gu [5], based on the interactive mechanism, influencing factors of "city-industry integration," the two subsystems of industrial function and urban function, analyzed the coupling and coordination of evaluation indicators by the entropy method. The consequences showed that the entropy method can better depict the "city integration" of the Kunshan Development Zone, which fits with reality; that is, relying on the early development of the old days. But with the massive influx of the migrant population, the "city integration" of Kunshan maintained a steady development and even decreased. Wu [6], took Yangquan City as an example, and the main component analysis method was used to reveal the development law of city-industry integration from 2004 to 2015. Through the coupling coordination model, countermeasures and suggestions were further compatible to the integration. The results presented that before 2009, the industrial development level of Yangquan City was faster than the urban development level, after which the industrial development level lagged behind the urban. Fan [7] constructed the evaluation system of the industrial development index, and used the entropy method to calculate the comprehensive industrial development index of Shandong Province. The urbanization coupling coordination degree model was established, which was used to calculate the coordination degree, and the spatial differences were analyzed. Bian [8], since constructing the evaluation index system of urbanization and ecological environment system, he used the coupling and coordination model to measure, trend, and analyze the comprehensive development level of urbanization and the ecological environment from 2009 to 2018 in Nanchang. Li [9] evaluated the new urbanization of 13 cities in the Beijing-Tianjin-Hebei region through constructing a novel evaluated system. He used coupling research to explore the coordinated development level of "production-living-ecological" space among cities. The conclusion mentioned that the development of this region was generally stable while severely polarized. The superiorities were not strong enough to drive peripheral cities [10–12].

It can be seen from the existing research literature that there are quantities of quantitative studies on the integration of industry and city, yet the idea is mainly to decompose the integration into industrialization and urbanization. Therefore, study the relationship between the two. On this basis, few researchers have introduced population and other factors to build a multilevel city-industry integration index system, and some researchers pay more attention to the quality of new urbanization. To sum up, the connotation of city-industry integration is rich, and the index system and methods are comprehensive. With ecological and environmental factors becoming crucial in recent years, it is necessary to introduce these two factors into the city-industry integration measurement index system. Building a ternary city-industry integration coupling and coordination measurement system, and further improving the research and city-industry integration measurement content.

2. Index System

Most of the previous city-industry integration measurement index system were divided into two aspects: urbanization and industrialization. With the increasing importance of the ecological environment to cities, this paper introduced the ecological environment-related indicators as a separate dimension and constructed the ternary city-industry integration coupling coordination measurement system, based on the indicators of urbanization and industrialization. When measuring the coupling and coordination degree of city-industry integration, the coordination between urbanization, industrialization, and the ecological environment was considered, and more emphasis on the importance of environmental protection. Therefore, the index system is keeping pace with the times (Table 1).

3. Entropy Method to Calculate the Comprehensive Score of Shanghai's Urbanization Subsystem, Industrialization Subsystem, and Ecological Environment Subsystem

3.1. Calculation Method: Entropy Method. Entropy is a physical measurement unit; the greater means, the more chaotic the data, the less information, the less utility value, and thus, the less weight. The entropy law is a method of combining the information value provided by entropy. The entropy method is calculated as follows [13, 14]:

(1) Select n years and m indexes, then the value of j in the year is i ($i=1, 2, \ldots, n$; $j=1,2, \ldots, m$).

(2) Normalization treatment of the indicators [15]: Homogeneity of heterogeneous indicators because the units of measurement of various indicators are not unified, so standardize them before using and solve the problem of homogenization of different quality indicators. Moreover, because the positive indicators and negative indicators represent different meanings (the higher the positive indicators, the better, and the lower the negative indicators, the better), we use different algorithms for high and low indicators. The specific methods are as follows:

$$\text{Positive indicator}: \; x'_{ij} = \frac{x_{ij} - \min x_{ij}, \ldots, x_{nj}}{\max x_{1j}, \ldots, x_{nj} - \min x_{1j}, \ldots, x_{nj}},$$
$$\text{Negative indicator}: \; x'_{ij} = \frac{\max x_{1j}, \ldots, x_{nj} - x_{ij}}{\max x_{1j}, \ldots, x_{nj} - \min x_{ij}, \ldots, x_{nj}}. \tag{1}$$

x_{ij} is the value of the jth index in the ith year ($i=1, 2, \ldots, n$; $j=1, 2, \ldots, m$) and the normalized data is x'_{ij}.

(3) Calculate the proportion of the ith country in item j indicator as follows:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}, \quad (i = 1, 2, 3, \ldots, n, \; j = 1, 2, 3, \ldots, m). \tag{2}$$

(4) Calculate the entropy of the item j index:

$$e_j \sum_{i=1}^{n} p_{ij} \ln\left(p_{ij}\right) = -k, \; (j = 1, 2, 3, \ldots, m). \tag{3}$$

Usually, k is valued as follows:

Table 1: City-industry integration coupling coordination degree measure index system of Shanghai.

		Metric	unit
Urbanization	people's life	Per capita GDP	Yuan per person
		Total retail sales of social consumer goods	Wan Yuan
	Urban size	GDP	Wan Yuan
		The natural growth rate of the registered population	‰
	Infrastructure	Total gas supply to LPG households	Ten thousand tons
		Road area	Million square meters
		Length of drainage pipe	kilometer
		Green area	hectare
		Park green area	hectare
		Domestic water supply quantity	One hundred million cubic meters
		Real estate development and investment	Wan Yuan
	Public service	The number of ordinary middle schools	The
		The number of ordinary primary schools	The
		Number of full-time teachers in ordinary middle schools	Human being
		Number of full-time teachers in ordinary primary schools	Human being
		Number of students in ordinary middle schools	Thousands of people
		Number of students enrolled in ordinary primary schools	Thousands of people
		The total amount of public libraries	Thousands of books
		Number of health personnel in hospitals and health centers	Human being
		Number of urban taxi operating vehicles	A car
		Total passenger transport of urban buses and trams	Ten thousand person-time
		General public budget revenue	Wan Yuan
		General public budget expenditure	Wan Yuan
		General public budget expenditure (education)	Wan Yuan
		General public budget expenditure (science and technology)	Wan Yuan
Industrialization	Industrial support	Share of the added value of the tertiary industry in GDP _	%
		Actual amount of foreign capital utilized (USD)	Ten thousand dollars
		The proportion of people employed in the tertiary industry in all urban units	%
Ecological condition	Ecological condition	Industrial waste gas treatment facilities	Cover
		Operation cost of industrial waste gas treatment facilities	Wan Yuan
		Number of nature reserves	Individual

$$k = \frac{1}{\ln(n)}, \left(0 \le e_j 1\right). \tag{4}$$

(5) Calculation of information entropy redundancy:

$$d_j = 1 - e_j. \tag{5}$$

(6) Calculate the weights of each indicator:

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j}. \tag{6}$$

(7) Calculate the composite score for each year:

$$S_i = \sum_{\mathrm{j=1}}^{\mathrm{m}} w_j p_{ij}. \tag{7}$$

The index data are multiplied by the corresponding weight, which is the "composite score."

3.2. Calculation Results. The data source of this paper is selected from Shanghai Statistical Yearbook from 2001 to 2018. The calculation results of the specific index weight and the comprehensive score of the three subsystems are as follows:

3.2.1. The Results of Urbanization Subsystem Calculation. In this paper, the entropy method is used to calculate the weight of 25 items including per capita GDP. As can be seen from Table 2, there is a certain difference in the weight of each index. General public budget expenditure (science and technology) has the highest weight of 0.168, followed by public budget revenue of 0.0957, public budget expenditure of 0.0939, and public budget expenditure (education) of 0.0907, indicating that the city's public budget revenue and expenditure factors present high weight. It is of great significance to promote the development and promotion of urbanization.

3.2.2. Calculation Results of the Industrialization Subsystem. Through the weight calculation of the added value of the tertiary industry in GDP, it can be seen from Table 3 that the proportion of the added value of the tertiary industry in GDP, the amount of foreign investment utilized (USD), and the proportion of the employment personnel in the tertiary

Table 2: Summary of weight calculation results calculated by the entropy method of urbanization index.

Metric	Information entropy value e	Information utility value d	Weight coefficient w (%)
Per capita GDP	0.9748	0.0252	3.28
Total retail sales of social consumer goods	0.9366	0.0634	8.27
GDP	0.9526	0.0474	6.19
The natural growth rate of the registered population	0.9501	0.0499	6.51
Total gas supply to LPG households	0.9961	0.0039	0.51
Road area	0.9816	0.0184	2.40
Length of drainage pipe	0.9551	0.0449	5.86
Green area	0.9251	0.0749	9.77
Park green area	0.9855	0.0145	1.90
Domestic water supply quantity	0.9957	0.0043	0.57
Real estate development and investment	0.9508	0.0492	6.42
The number of ordinary middle schools	0.9995	0.0005	0.06
The number of ordinary primary schools	0.9986	0.0014	0.18
Number of full-time teachers in ordinary middle schools	0.9993	0.0007	0.10
Number of full-time teachers in ordinary primary schools	0.9955	0.0045	0.59
Number of students in ordinary middle schools	0.9973	0.0027	0.36
Number of students enrolled in ordinary primary schools	0.9956	0.0044	0.58
Total amount of public libraries	0.9979	0.0021	0.27
Number of health personnel in hospitals and health centers	0.9909	0.0091	1.19
Number of urban taxi operating vehicles	0.9996	0.0004	0.05
Total passenger transport of urban buses and trams	0.9989	0.0011	0.14
General public budget revenue	0.9267	0.0733	9.57
General public budget expenditure	0.9281	0.0719	9.39
General public budget expenditure (education)	0.9305	0.0695	9.07
General public budget expenditure (science and technology)	0.8713	0.1287	16.80

Table 3: Summary of weight results calculated by entropy method of industrialization index.

Metric	Information entropy value e	Information utility value d	Weight coefficient w (%)
Share of the added value of the tertiary industry in GDP _	0.9967	0.0033	6.22
The actual amount of foreign capital utilized (USD)_	0.9536	0.0464	88.62
Proportion of employed personnel in the tertiary industry in all urban units	0.9973	0.0027	5.15

Table 4: Summary of weight results by entropy method.

Metric	Information entropy value e	Information utility value d	Weight coefficient w (%)
Industrial waste gas treatment facilities	0.9826	0.0174	20.92
The operation cost of industrial waste gas treatment facilities	0.9355	0.0645	77.62
Number of nature reserves	0.9988	0.0012	1.46

industry in all urban units are 0.0622, 0.8862, and 0.0515, respectively. There are significant differences in the weight of each index, among which the weight of the actual amount of foreign capital utilized (USD) is the highest at 0.886.

3.2.3. Results of the Ecological Environment Subsystem Calculation. Through the weight calculation of a total of 3 industrial waste gas treatment facilities, it can be seen from Table 4: The weights of industrial waste gas treatment facilities, operation cost, and number of nature reserves are 0.209, 0.776, and 0.015, respectively. There are significant differences among the indicators, among which the highest operating weight of industrial waste gas treatment facilities is 0.7762, followed by industrial waste gas treatment facilities is 0.2092, and finally the lowest weight of nature reserves is 0.0146.

Table 5: Comprehensive scores of the three subsystems of urbanization, industrialization, and ecological environment in Shanghai.

A particular year	The urbanization subsystem, U_1 comprehensive score	Industrial subsystematization U_2 comprehensive score	Eco environment subsystem U_3 comprehensive score
2001	6069465.255277042	288030.7076	35148.80034
2002	6847851.752261051	665574.5625	64602.02697
2003	8003557.583150507	426125.8083	64940.81878
2004	9581896.351504287	322408.8085	72557.15126
2005	1.1594391653341206	270107.9047	86979.78213
2006	1.2960416753937133	388665.4071	147126.1251
2007	1.5854396212812783	443915.1551	140714.6906
2008	1.8107000088566244	517683.3243	133506.2852
2009	2.022367529536539	579322.4914	172279.2941
2010	2.3216090097987592	606405.5765	224993.1545
2011	2.6381771796085086	629850.1579	324050.7656
2012	2.827606545987435	701870.7762	315366.6283
2013	3.0701497179833263	893718.8493	366977.2973
2014	3.39852693263683	933961.8638	314499.5489
2015	3.79384749172154	985636.8879	336985.9069
2016	4.286149582565541	1116722.792	346316.6738
2017	4.6134768184931695	1345726.521	409082.0402
2018	4.951112283676133	1487087.421	414786.87

3.2.4. Results of the Comprehensive Score Calculation for the Three Subsystems. After multiplying the index data with the corresponding weight, the comprehensive score of the system is obtained as follows (Table 5):

4. Analysis of the Coupling Coordination Degree of City-Industry Integration in Shanghai

4.1. Coupling Coordination Degree Model. The key to the accurate mechanism lies in the synergy between the order parameters within the system. The coupling degree is the measure of this synergy. In the comparative analysis of the coupling degree, merely relying on the coupling degree model cannot reflect the coordination of urbanization, industrialization, and the ecological environment [16–18]. As a supplement to the coupling degree, there is the concept of coordination, which is used to reflect the benign interactions between the subsystems. The two concepts (coupling degree and coordination) generally measure the harmony degree among the internal subsystems in the process of the coupling coordination degree, which reflects the transition trend of the system orderly [19]. The advantage of the coupling coordination model is that it can measure not only the coordination degree between the subsystems but also the coordination degree between all the factors within the subsystem. Therefore, the coupling coordination model measures the ternary coordination relationship among urbanization, industrialization, and the ecological environment.

(1) Degree of coupling C. The calculation formula is as follows:

$$C = \sqrt[3]{\frac{u_1 * u_2 * u_3}{(u_1 + u_2 + u_3/3)^3}}. \tag{8}$$

In the formula u_1 is the comprehensive score of the urbanization subsystem, u_2 is the comprehensive score of the industrialization subsystem, and u_3 is the comprehensive score of the ecological environment subsystem.

(2) Integrated Coordination Index. The calculation formula is as follows:

$$T = \beta_1 U_1 + \beta_2 U_2 + \beta_3 U_3. \tag{9}$$

In the formula, β_1, β_2, and β_3 represent the weight of the subsystem, as set up in this article, $\beta_1 = \beta_2 = \beta_3$.

(3) The value of the coupling coordination degree D. The calculation formula is as follows:

$$D = \sqrt{C * T}. \tag{10}$$

4.2. Calculation Results. In this paper, the index data is first interval so that all the data are between 0 and 1, and then the processed data are used for a formal coupling coordination study. Data internalization is to \compress the data between [0.01, 0.99] by a + (b − a) ∗ (X − Min)/(Max − Min), where b is 0.99 and a is 0.01, and max and min indicate the corresponding maximum and minimum values of a term, respectively [19]. The calculation results of city-industry fusion coupling coordination degree are as follows:

As can be seen from Tables 6 and 7, the curve rose from 2001 to 2002 before decreasing until 2005. There was a constant rise in the coupling coordination degree of the city-industry integration of Shanghai to 2018. It increased from 0.116 (2001) to 0.995 in 2018; therefore, it belongs to the quality coordination level (level 10). Hence, the coordination between urbanization, industrialization, and the ecological environment increases annually in Shanghai. Not only are the people's happiness, urban scale, infrastructure, public services, and industrial support between two factors and

Table 6: Calculation results of city-industry integration in Shanghai.

year	C value of coupling degree	Coordination Index T value	Coupling coordination degree D value	Coordination level	The degree of coupling coordination
2001.0	0.909	0.015	0.116	2	Major maladjustment
2002.0	0.624	0.147	0.303	4	Mild dysregulation
2003.0	0.932	0.092	0.293	3	Moderate dysregulation
2004.0	0.958	0.083	0.281	3	Moderate dysregulation
2005.0	0.602	0.096	0.241	3	Moderate dysregulation
2006.0	0.913	0.190	0.416	5	On the verge of dysregulation
2007.0	0.967	0.221	0.462	5	On the verge of dysregulation
2008.0	0.992	0.252	0.500	5	On the verge of dysregulation
2009.0	0.990	0.317	0.561	6	Forced coordination
2010.0	0.973	0.393	0.618	7	Primary coordination
2011.0	0.932	0.508	0.688	7	Primary coordination
2012.0	0.958	0.534	0.715	8	Intermediate coordination
2013.0	0.973	0.648	0.794	8	Intermediate coordination
2014.0	0.993	0.638	0.796	8	Intermediate coordination
2015.0	0.992	0.701	0.834	9	Good coordination
2016.0	0.996	0.782	0.883	9	Good coordination
2017.0	0.999	0.922	0.960	10	Quality coordination
2018.0	1.000	0.990	0.995	10	Quality coordination

Table 7: Classification criteria of coupling coordination degree.

Coupled coordination degree D value interval	Coordination level	The degree of coupling coordination
(0.0~0.1)	1	Extreme disorder
[0.1~0.2)	2	Major maladjustment
[0.2~0.3)	3	Moderate dysregulation
[0.3~0.4)	4	Mild dysregulation
[0.4~0.5)	5	On the verge of dysregulation
[0.5~0.6)	6	Forced coordination
[0.6~0.7)	7	Primary coordination
[0.7~0.8)	8	Intermediate coordination
[0.8~0.9)	9	Good coordination
[0.9~1.0)	10	Quality coordination

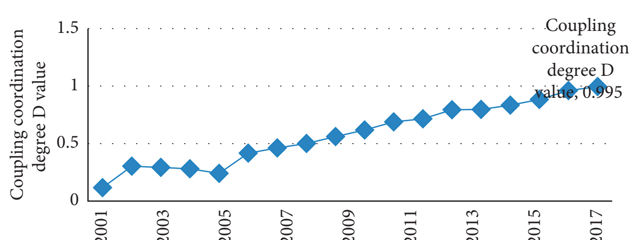

Figure 1: D value of the city-industry integration coupling coordination degree in Shanghai.

internal factors of higher but also the relationship between these factors and ecological environmental factors is more harmonious.

By Figure 1, Shanghai city-industry integration coupling coordination---D value curve trend can be seen: in addition to 2003 to 2005, the trend is overall rising in the statistical period (from 2001 to 2018), especially from 2005 to 2006. Shanghai's urbanization, industrialization, and the ecological environment from 2005 to 2018 has been steadily improved: city-industry integration has become higher and urban function has performed more perfectly with a well-managed ecological environment.

5. Conclusion

This paper focuses on the measurement of Shanghai city-industry integration, based on urbanization and industrialization. Then the paper introduces the importance of the ecological environment, emphasizing the crucial integration in the process of ecological civilization. So that builds the ternary coupling coordination measurement model and uses entropy method to determine the weight and comprehensive score. And finally, by utilizing the coupling coordination measurement, we reached the following conclusion: (1) Shanghai's public budget revenue and expenditure factors have significant meaning to promote the development and promotion of urbanization. (2) The operation cost of Shanghai industrial waste gas treatment facilities and their input is crucial for the protection of ecological environment. (3) The degree of coordination between urbanization, industrialization, and ecological environment in Shanghai was relatively low from 2001 to 2005. (4) From 2006 to 2018, coordination among urbanization, industrialization, and the ecological environment in Shanghai has continuously improved until 2017 and 2018, when reached the highest level of coordination. Now, people's happiness, urban scale, infrastructure, public services, industry support, and ecological environment factors as well as all other factors within the system are highly coordinated.

Data Availability

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

Conflicts of Interest

Authors declare that they have no conflicts of interest.

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