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Measurement and Spatial Difference Analysis of the Development Level of Urban Solid Waste Resource Utilization from the Perspective of "Waste-Free City"

-- Based on the Empirical Research in Yangtze River Delta Region

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Abstract

While the domestic economy is developing rapidly, the impact of municipal solid waste on the ecological environment is increasing. The construction of "waste-free cities" has become an inevitable choice and an important tool to promote the sustainable development of cities and the sustainable management of solid waste. This paper evaluates the level of solid waste resource utilization in 27 central cities in the Yangtze River Delta region from four dimensions: technical level, economic benefit, social benefit and environmental protection benefit. Firstly, the gray correlation is used to calculate the gray correlation between the selected indicators and the green low-carbon city index, and the results show that the gray correlation of all the indicators is greater than 0.80, which has strong explanatory ability. Then, the entropy weighting method was used to calculate the weights of the indicators and the comprehensive score of the cities, and the top five cities in the comprehensive score were Shanghai, Suzhou, Hangzhou, Ningbo and Nanjing. Then, by comparing the average scores of Shanghai, Jiangsu Province, Zhejiang Province and Anhui Province, the difference analysis is carried out, and it is found that the regional economic level and industrial structure are the main factors affecting the development level of municipal solid waste resourceization. Finally, the results of the empirical analysis are combined to make suggestions for the construction of "waste-free cities" in China.

Keywords

Waste-free City; Municipal Solid Waste Resources; Gray Correlation; Entropy Power Method.

1. Introduction

In recent years, the State has been promoting the pilot program of "Waste-Free Cities". Among the many pilots, the Yangtze River Delta (YRD) is one of the regions with the most active economic development, the highest degree of openness, and the strongest innovation capacity in China, and has a pivotal strategic position in the overall situation of the country's modernization and all-round opening pattern. The YRD region is also facing severe resource and environmental pressures, such as infrastructure development, in the context of high-

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quality economic development. Many municipal solid waste treatment facilities in the YRD region are operating at full capacity or overload. Xuzhou City, Jiangsu Province, Shaoxing City, Zhejiang Province, and Tongling City, Anhui Province, which are located in the Yangtze River Delta cluster, are among the "11 + 5" pilot cities and regions in the country, and the three municipalities have established different management modes and are gradually extending to other municipalities in the Yangtze River Delta region. The three cities have established different management models and gradually extended them to other cities in the Yangtze River Delta region. Therefore, this study is mainly based on the Yangtze River Delta region, and analyzes the current situation and influencing factors to provide suggestions for the promotion of "waste-free cities" in the Yangtze River Delta region, and to help the smooth promotion of "waste-free cities".

2. Current Status of Domestic and International Research

In recent years, some countries and regions have carried out the exploration of "Zero-waste City" (Zero-waste City). 23 cities in the C40 Cities Group have signed the "Towards Zero Waste Declaration"; Vancouver, Vancouver, Kapanori, San Francisco, Sydney, Oakland and other cities have clearly put forward the blueprint for the construction of "Zero-waste city"; the United Nations Human Settlements Programme has released the "Smart Waste Reduction Cities Campaign"; and Singapore will promulgate the "Zero-waste City" (ZWCC) plan in 2019 to move towards ZWCC. In 2019, Singapore will promulgate a national vision towards "zero waste" as one of the key strategies for building a sustainable, resource-efficient and climate-resilient nation. The construction of "waste-free cities" has become an inevitable choice and an important tool for promoting sustainable urban development and the sustainable management of solid waste.

The concept of "waste-free city" in China was proposed in 2017, and Academician Du Xiangwan of the Chinese Academy of Engineering took the lead in putting forward the "Suggestions on Promoting the Resourceful Utilization of Solid Waste through the Pilot Project of Waste-Free City to Build a Waste-Free Society", pointing out that the pilot project should be carried out in cities, and that we should start from the "waste-free city" to ultimately realize the "waste-free society".

In December 2020, the first batch of pilot construction of "waste-free cities" in China came to an end, achieving phased results, but there are also some practical problems. In the future, further in-depth and systematic promotion of China's "waste-free city" construction is still facing many challenges, such as the lack of strategic planning and top-level design, poor operation of the management system, inadequate legal and regulatory system, imperfect economic incentives and market-oriented mechanism, and insufficient technological innovation.

In establishing the evaluation system, China mostly adopts comprehensive evaluation methods, mainly including factor analysis method, hierarchical analysis method, fuzzy comprehensive evaluation method, gray correlation method, TOPSIS method and entropy weight method. Scholar Wen Jixin (2023) mainly used entropy weight-TOPSIS method to establish Xuzhou comprehensive evaluation index to determine the development status in his research. For the influencing factors mainly based on questionnaire data and official collection data to establish a model to analyze the specific influencing factors. Wen Huwei (2020) collected a large amount of official data by using Stata 15.0 analysis software, using the systematic GMM method to estimate the parameters of the dynamic panel regression model. And thus analyzed the specific influencing factors are high-tech, resource tax and so on.

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3. Research Methodology and Data Sources

3.1. Research Design

3.1.1. Gray Correlation Model

The calculations are as follows.

(1) Determine the analysis sequence

Parent Sequence: $X_0 = \left(x_0^{(1)}, x_0^{(2)}, \ldots, x_0^{(n)}\right)$

Subsequence: $(X_1, X_2, \ldots, X_m) = \begin{bmatrix} x_1^{(1)}, x_2^{(1)}, \ldots, x_m^{(1)} \\ x_1^{(2)}, x_2^{(2)}, \ldots, x_m^{(2)} \\ \cdots \\ x_1^{(n)}, x_2^{(n)}, \ldots, x_m^{(n)} \end{bmatrix}$

(2) Programmability of indicators

$$x_i'^{(k)} = \frac{x_i^{(k)}}{\frac{1}{n}\sum_{k=1}^{n} x_i^{(k)}}, i = 1,2,\ldots,m, k = 1,2,\ldots,n$$

(3) Calculate the correlation coefficient of each indicator in the subseries with the parent series

$$\delta_{0i}(k) = \frac{\alpha + \rho\beta}{\left|\mathrm{x}_0^{(\mathrm{k})} - \mathrm{x}_\mathrm{i}^{(\mathrm{k})}\right| + \rho\beta}$$

Among them, $\left|\mathrm{x}_0^{(\mathrm{k})} - \mathrm{x}_\mathrm{i}^{(\mathrm{k})}\right|$ is the absolute difference between the dimensionless data of the parent series and the comparison series; α is the lesser of two levels, $\alpha = \min\left|\mathrm{x}_0^{(\mathrm{k})} - \mathrm{x}_\mathrm{i}^{(\mathrm{k})}\right|$; β is the larger of the two levels, $\beta = \max\left|\mathrm{x}_0^{(\mathrm{k})} - \mathrm{x}_\mathrm{i}^{(\mathrm{k})}\right|$; ρ is the resolution factor. The range of values is (0,1),ordinary course of action $\rho = 0$.

(4) Calculating Gray Correlation γ_i

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \delta_{0i}(k)$$

3.1.2. Entropy Wighting Model

The calculations are as follows:

(1) Construction of the evaluation matrix X

Let the number of evaluation objects be m, the number of evaluation indicators be n, and the evaluation matrix be:

$$\mathrm{X} = \left(\mathrm{x_{ij}}\right)_{\mathrm{m}\times\mathrm{n}}, \mathrm{i} = 1,2,\ldots,\mathrm{m}; \mathrm{j} = 1,2,\ldots,\mathrm{n}.$$

(2) Data standardization

Standardization of positive indicators: $a_{ij} = \frac{x_{ij} - min\{x_{1j},\ldots,x_{nj}\}}{max\{x_{1j},\ldots,x_{nj}\} - mi\ \ \{x_{1j},\ldots,x_{nj}\}}$

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Standardization of negative indicators: $a_{ij} = \frac{max\{x_{1j}-x_{nj}\}-x_{ij}}{max\{x_{1j},\ldots,x_{nj}\}-min\{x_{1j},\ldots,x_{nj}\}}$

(3) Calculate the entropy of each evaluation index e_j

$$p_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$$

$$e_j = -\frac{1}{\ln n}\sum_{i=1}^{n} p_{ij} \ln p_{ij}$$

If $p_{ij} = 0, p_{ij} \ln p_{ij} = 0$.

(4) Calculation of the coefficient of variation for each indicator g_j

$$g_j = 1 - e_j$$

(5) Calculation of the weights of the indicators

$$w_j = \frac{g_j}{\sum_{j=1}^{m} g_j}$$

(6) Calculate the composite score for each evaluator

$$s_i = \sum_{j=1}^{m} w_j p_{ij}$$

3.1.3. Data Selection and Pre-processing

The data used in this paper come from the China Statistical Yearbook published by the National Bureau of Statistics in 2023 and the official websites of Jiangsu, Zhejiang and Anhui Statistical Bureaus. For some of the missing data this paper adopts the mean value filling method, and all the data are standardized to eliminate the influence of the magnitude and order of magnitude on the model results, and finally caollate the data of 27 central cities in China's Yangtze River Delta region in 2022.

3.1.4. Selection of Evaluation Indicators

In this paper, the development level of solid waste resource utilization in cities in the Yangtze River Delta region is comprehensively considered from four dimensions: technical level, economic benefit, social benefit and environmental protection benefit. The explanation of specific variables is shown in Table 1.

In summary, this paper establishes and constructs a comprehensive evaluation system for the development level of municipal solid waste resource utilization, including 4 first-level indicators: technical level, economic benefit, social benefit and environmental protection benefit, and 11 second-level indicators: capacity of harmless treatment of domestic garbage, capacity of harmless treatment of industrial garbage, capacity of wastewater treatment, GDP per capita, disposable income per capita, financial expenditure on environmental protection, number of employed persons, number of employed persons, consumer price index, green area of park per capita, air and pollution control, total water supply, number of personnel, consumer price index, green space per capita in parks, air and pollution control, and total water supply. The details are shown in Table 2.

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Table 1. Explanatory notes on indicators

Indicator	Indicator	Explanatory Notes
x_1	Harmless treatment capacity of domestic waste	Harmless treatment rate of domestic garbage
x_2	Harmless treatment capacity of industrial waste	Comprehensive utilization rate of general industrial solid waste
x_3	Sewage treatment capacity	Daily treatment capacity of municipal wastewater facilities
x_4	GDP per capita	GDP per capita
x_5	Per capita disposable income	Per capita disposable income
x_6	Financial Expenditure on Environmental Protection	General public expenditure on energy conservation and environmental protection services
x_7	Number of employed persons	Number of employed persons
x_8	Consumer Price Index	Consumer Price Index
x_9	Green space per capita	Green space per capita
x_{10}	Atmosphere and Pollution Control	Proportion of days with air quality at or better than Level 2
x_{11}	Total Water Supply	Total annual urban water supply

Table 2. Evaluation system for the development level of municipal solid waste resource utilization

	Dimension	Indicator	Unit	Causality
Comprehensive Evaluation System for the Development Level of Municipal Solid Waste Resource Utilization	Technology Level	x_1	%	+
		x_2	% of the total number	+
		x_3	Million tons/day	+
	Economic Benefits	x_4	Yuan	+
		x_5	Yuan	+
		x_6	million yuan	+
	Social Benefits	x_7	million	+
		x_8	%	+
	Environmental Benefits	x_9	Square meter/person	+
		x_{10}	%	+
		x_{11}	billion cubic meters	+

In this paper, before the empirical analysis, the data of each index were analyzed by descriptive statistics. It can be intuitively seen that most of the maximum and minimum values of the data of each indicator do not differ much, indicating that there is no extreme abnormality occurring in the sample data and the data are credible. The maximum value of the variable local financial expenditure on environmental protection is 2038100, and the minimum value is 31021, which is obviously a large difference between the variable samples.

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Table 3. Descriptive statistics

Indicator	Sample Size	Minimum	Maximum	Mean	Deviation
x_1	27	0.98	1.00	1.00	0.00
x_2	27	0.75	1.10	0.94	0.07
x_3	27	8.30	896.80	151.50	185.03
x_4	27	66470	198404	129816.85	39110.17
x_5	27	28802.50	79610	46742.82	12758.81
x_6	27	31021	2038100	276351.40	382297.24
x_7	27	26.55	758.64	317.85	221.21
x_8	27	101.60	102.50	102.13	0.23
x_9	27	9.28	26.53	15.96	3.21
x_{10}	27	0.78	0.98	0.85	0.05
x_{11}	27	1.25	32.98	14.94	10.27

3.2. Model Solving Results and Analysis

This paper firstly establishes a gray correlation model by taking the green low-carbon city index as a comparative sequence and 11 indicators as sub-sequences. Explore whether the selected indicators can have a better evaluation of the development level of solid waste resource utilization in cities. Then the entropy weighting model is established to calculate the weights and comprehensive scores of the cities and analyze the spatial differences by comparing the comprehensive scores of the four regions.

The results of the software solution show that the gray correlation between all the indicators and the green low-carbon city index is greater than 0.80, indicating that the selected indicators have a high degree of interpretation. Among them, the gray correlation between the capacity of harmless treatment of domestic waste, the capacity of harmless treatment of industrial waste and the consumer price index is the highest, which is 0.9865, 0.9806 and 09872 respectively. The specific numerical results are shown in Table 4.

Table 4. Gray correlation results

Indicator	Gray Correlation
Harmless treatment capacity of domestic waste	0.9865
Harmless treatment capacity of industrial waste	0.9806
Sewage treatment capacity	0.8084
GDP per capita	0.9325
Per capita disposable income	0.9369
Financial Expenditure on Environmental Protection	0.8200
Number of employed persons	0.8836
Consumer Price Index	0.9872
Green space per capita	0.9527
Atmosphere and Pollution Control	0.9775
Total Water Supply	0.8148

The three indicators of local financial expenditure on environmental protection, sewage treatment capacity and number of employed persons have the largest weights, which are 0.2148, 0.1965 and 0.1079, respectively. The specific solution results are shown in Table 5.

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Table 5. Entropy weighting method weighting results

Indicator	Weight
Harmless treatment capacity of domestic waste	0.0127
Harmless treatment capacity of industrial waste	0.0313
Sewage treatment capacity	0.1965
GDP per capita	0.0721
Per capita disposable income	0.0837
Financial Expenditure on Environmental Protection	0.2148
Number of employed persons	0.1079
Consumer Price Index	0.0427
Green space per capita	0.0383
Atmosphere and Pollution Control	0.0921
Total Water Supply	0.1079

The results of the composite score calculation are shown in Table 6, from which it can be visualized that the top 10 cities are Shanghai 0.1504, Suzhou 0.0613, Hangzhou 0.0610, Ningbo 0.0552, Nanjing 0.0544, Hefei 0.0463, Wuxi 0.0456, Ma'anshan 0.0428, Wuhu 0.0418, and Wenzhou 0.0401. The maximum composite score of 0.1504 is for Shanghai, and the minimum composite score of 0.0117 is for Chizhou. has the largest composite score of 0.1504, Chizhou has the lowest composite score of 0.0117, and the overall average is 0.0370.

Table 6. Composite score

City	Composite Score	City	Composite Score
Shanghai	0.1504	Jinhua	0.0297
Suzhou	0.0613	Jiaxing	0.0293
Hangzhou	0.0610	Zhoushan	0.0255
Ningbo	0.0552	Yangzhou	0.0231
Hefei	0.0544	Zhenjiang	0.0222
Hefei	0.0463	Huzhou	0.0210
Wuxi	0.0456	Xuancheng	0.0208
Maanshan	0.0428	Taizhou	0.0198
Wuhu	0.0418	Yancheng	0.0193
Wenzhou	0.0401	Anqing	0.0192
Taizhou	0.0329	Chuzhou	0.0188
Changzhou	0.0327	Tongling	0.0139
Shaoxing	0.0314	Chizhou	0.0117
Nantong	0.0302	Average	0.0370

By calculating and comparing the average, maximum and minimum values of the comprehensive evaluation scores of the development level of municipal solid waste resource utilization in Shanghai, Jiangsu, Zhejiang and Anhui provinces, we can find that the average value of the comprehensive score in Shanghai is the highest at 0.1504, followed by 0.0362 in Zhejiang, 0.0343 in Jiangsu and 0.0269 in Anhui.

From a macroscopic point of view, Shanghai, Zhejiang Province and Jiangsu Province belong to the eastern region of China by virtue of its superior geographic advantages and related policy support is more likely to make progress in the construction of waste-free cities, while Anhui Province belongs to the central region of China, the economic strength of the medium, the

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construction of waste-free cities in the early stages of the need for a large number of manpower and material resources investment.

In terms of industry type, the GDP of tertiary industry in Shanghai accounted for 75.2% in 2023, and its GDP was mainly contributed by the high-tech industry and non-material production sector, and the GDP contribution of secondary industry in Anhui province was the largest of 57.4% in 2022, which indicated that the GDP of Anhui was mainly composed of the manufacturing industry, the construction industry and the industry. In turn, industrial solid waste and construction waste are the main types of municipal solid waste resources.

In summary, there are certain spatial differences in the development level of municipal solid waste resource utilization in the Yangtze River Delta region Specific results are shown in Table 7.

Table 7. Comparison of the combined scores of the four regions

Region	Average	Max	Min
Shanghai	0.1504	0.1504	0.1504
Jiangsu Province	0.0343	0.0613	0.0193
Zhejiang Province	0.0362	0.0610	0.0210
AnhuiProvince	0.0269	0.0463	0.0117

4. Suggestion

4.1. Establish an Efficient Solid Waste Resource Utilization System

Reducing waste generation radically is crucial to the high-quality development of the city's circular economy. Taking into account the actual situation in the Yangtze River Delta, the following specific initiatives may be needed to move forward at present.

First, the relevant authorities need to guide enterprises to transform their production technologies in order to reduce the amount of solid waste substances generated and strengthen the control of solid waste substances from the root. At the same time, renewable and recyclable biodegradable materials should be fully utilized, and a closed-loop production cycle should be implemented throughout the value chain. By reducing costs and improving predictability and control in the production cycle, we can further realize the effective use and recycling of resources. This will not only help to reduce waste generation, but also improve productivity and resource utilization.

Secondly, waste sorting centers can be set up in cities to separate waste, thereby increasing the utilization value of general solid waste materials and strengthening cost control of mixed waste disposal. At the same time, ways should be found to ensure that solid waste is recoverable and collectible. Key to this is the integration of industrial production and consumption into the same system to ensure that industrial products are recycled and reused in a timely manner at the "end of the line". In addition, wastes and by-products generated in the production process of waste recovery should be effectively recycled, which requires the establishment of sound recycling systems and the strengthening of research and development on waste reuse technologies.

4.2. Strengthen Regulation and Governance of Solid Waste Resource Utilization

A relatively complete solid waste resource utilization system also needs to be matched with effective governance instruments and tools to effectively strengthen legal regulation and multi-stakeholder collaborative governance.

In order to strengthen the compliance and effectiveness of the resource utilization of solid waste in the construction of a "waste-free city", legislative support must be strengthened. At

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present, it is necessary to formulate and improve relevant laws, regulations and standards in the areas of production design, packaging restrictions, article disposal, resource recycling and reclamation, to clarify the responsibilities and obligations of the Government, enterprises and individuals, and to establish positive incentives and penalties.

It is also necessary to promote the formation of a multi-stakeholder synergistic model in which "Government + producers + consumers" share the burden. The overall scale of solid waste resource utilization should be scientifically planned, and "localized" and "localized" resource utilization should be achieved, with distributed utilization and digestion promoted. On this basis, it is also necessary to establish a value identification mechanism to accurately identify and measure the value gain of solid waste, so as to provide economic support for resource utilization.

4.3. Enhance the Basic Capacity of Solid Waste Resource Utilization

In view of the actual situation in the Yangtze River Delta region, a series of measures are also needed to enhance the basic capacity for the resource utilization of solid waste.

First of all, strengthen the technological research and development of the resource utilization of solid wastes. This includes strengthening the research and development of process technology, miniaturization, distributed processing equipment and technology, as well as the research and development of intelligent technology throughout the entire process. At the same time, it is necessary to focus on the research and development of early warning technology, which can timely detect and correct irregularities, irregular operations and statistical errors. In addition, the technology for comprehensive analysis and utilization of big data needs to be improved in order to enhance the science and precision of solid waste management.

Secondly, it is necessary to promote the rational transformation of resource utilization technologies, establish functional platforms and service bases for the transformation and transfer of comprehensive resource utilization technologies, and focus on supporting the research and development and demonstration application of platform construction, screening technologies, gradient utilization and recycling technologies, forming a mastery of key green technologies in related fields and enhancing technical service capabilities in order to promote the rapid promotion and application of resource utilization technologies.

On this basis, it is also necessary to coordinate regional resources and open up the recycling and disposal industry chain. A regularized and long-term cooperation mechanism should be established, and a regionally unified standard system for resource utilization should be studied in order to effectively break through administrative policy barriers and market barriers. Only by strengthening cooperation and breaking down all kinds of barriers can we achieve the maximization and optimization of solid waste resource utilization.

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