Research Article

Measuring Zero-Waste City Performance of a Coal Resource-Based Area in China with MCDM Approach

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The zero-waste city is one of the most visionary initiatives for solving waste problems by enhancing the life cycle solid waste management system. However, the development level of ZW city construction remains unclear. Resource-based areas tend to produce large amounts of industrial solid waste, and achieving a zero-waste city is difficult due to insufficient resource utilization capacity. This study proposed a practical integrated MCDM approach to assess the performance of the ZW city and applied the approach to a typical coal resource-based province in China. The spatiotemporal characteristics and factors influencing the performance of zero-waste cities in each city were further explored. The performance levels increased during the study period; however, the growth rate of most cities is slow. Spatially, the performance levels of zero-waste cities gradually decreased from south to north, showing a radiation pattern with Taiyuan at its core. Challenges toward zero-waste city development were further identified, including heavy industrial structure, widespread underutilization of industrial solid waste, inadequate management of hazardous solid waste, low rate of urban domestic waste classification, and ineffective treatment. The approach gives a holistic and broader picture of the zero-waste management performance, which enables us to identify the challenges in promoting zero-waste cities.

1. Introduction

Cities around the world are rapidly growing, consuming large amounts of resources while generating serious waste pressure. It is projected that the global solid waste will increase by 70% to 3.4 billion tons in 2050, and the growing trends are sharper particularly in developing countries [1]. The increasing volume and complexity of the waste pose serious issues over societal, economic, health, and environmental concerns [2–4]. Solid waste management (SWM) is considered as one of the most important provisions to tackle the waste problem. Studies have addressed that a well-designed SWM has multiple positive outcomes including energy and resource saving, economic and health benefits, as well as GHG reduction [5–7].

Zero waste (ZW) is one of the most visionary initiatives for managing solid waste problems. It is a set of strategies that aim to minimize the environmental impacts by integrating waste reduction, recycling, and advanced waste treatment [8]. The ZW concept was first proposed by Paul Palmer in 1973 [9] and then embraced by a growing number of countries as it transforms the "end-of-pipe" solution to life cycle waste management [8, 10]. Policies, laws, and market measures were applied and integrated to promote zero-waste practices. In 1995, Canberra was the first city to announce the “zero-waste city” mission [11]. Japan established the “Zero Waste Research Institute” to promote the development of a circular society. International organizations such as “Zero Waste International Alliance (ZWIA)” and “Zero Waste Europe (ZWE)” are encouraging the whole society to participate in waste management and resource management. As the second largest economy in the world, China is determined to promote waste recycling and circular economy to deal with the challenges of both economic growth and environmental protection [12]. The state council of China issued a “zero-waste city” pilot program in 2018 to
2 Mathematical Problems in Engineering

guide comprehensive solid waste management in eleven pilot cities [13]. Though many cities have committed to ZWC goals and there have been some successful practices of ZWC management, their performances are significantly different. Studies show that the performances of waste management systems vary with economic status, institutional background, and participative strategies in different regions [14–16]. In developing countries, waste management is generally inefficient due to the high cost of equipment, inadequate resource utilization, and disposal capacity or policy barriers [17–20]. Thus, it is essential to have scientific support from comprehensive evaluation to increase the sustainable performance of ZWC [21].

The ZWC is a holistic waste management system that requires a reliable performance measurement mechanism. Life cycle analysis (LCA) is widely applied to better understand the environmental performance of solid waste management [22–24]. Material flow analysis is another frequently used method to quantify the performance of waste management. For instance, Wang et al. [25] combined material flow analysis and LCA to assess the improvements of the SWM system in Nottingham, UK. Data envelopment analysis (DEA) is considered as an important tool to measure the efficiency of solid waste management [15, 26]. There are also studies that developed a waste-related index, which can simply the measurement of a complex waste management system [27, 28]. However, these methods focus on the effectiveness and outcomes of solid waste management, while the underlying factors that influence the performance are not well evaluated. Some previous efforts highlight the decision-making contexts, such as policy and regulation perspectives, and are accountable for the sustainable performance of waste management [29–32]. Indicators involved in the assessment should reflect concerns related to social, economic, environmental, and policy domains [20, 33–35]. Therefore, measuring the performance of ZWC development generally has multiple objectives and criteria [36]. The multicriteria decision-making (MCDM) method has proven to be a complex tool to balance the goals that regard a problem, which is applied in our study to further explore the holistic performance of ZWC.

The coal resource-based areas are clustered by coal mining-related industries [37], and the resource-dependent economies tend to generate more industrial solid waste [38, 39]. The challenges toward ZWC in resource-based areas are emphasized by previous studies [40–42]. However, most empirical research studies on performance assessment in China focus on pilot cities [43–45], and the approach to evaluate the performances of ZWC in resource-based areas is still a pending issue. The aim of the study is to propose a practical, holistic evaluation approach to measure the performance of ZWC based on the MCDM method. We developed a comprehensive evaluation index system by integrating the life cycle of solid waste management objectives and policy background. The approach was applied to Shanxi province, a typical coal-based region and a national resource-based economic transformation pilot zone in China. The ZWC performances in prefectural cities of Shanxi province were evaluated, and the policy implications to improve zero-waste cities were further explored. The study may contribute to a more holistic and broader picture of ZWC performance in coal resource-based cities, which would be useful to better understand the mechanism and problems in ZWC in developing countries.

2. Materials and Methods

2.1. Data Source. The eleven prefecture-level cities of Shanxi province, Taiyuan, Datong, Yangquan, Changzhi, Jinzhong, Shuozhou, Jinzhong, Yuncheng, Xinzhou, Linfen, and LONGLIANG were selected as research areas.


2.2. Construction of the Index System. Shanxi province is a traditional coal-resource region in China, which consists of a large proportion of heavy industry, leading to rapid production of industrial solid waste. However, insufficient treatment of industrial solid waste and inadequate supervision system seriously restrict Shanxi province’s economic development.

This study follows the principles of scientific, representative, and operable to construct the index system. The evaluation system is constructed for the purpose of encouraging green production and lifestyle; it takes account of the continuous promotion of minimizing the amount of solid waste produced and resource utilization as the core goal. Based on the index for zero-waste cities construction in pilot cities which proposed by the Ministry of Ecology and Environment of the People’s Republic of China in 2018, as well as the waste management background in Shanxi province, the indicators are selected from four aspects: reduction of solid waste, utilization of solid waste, final disposal of solid waste, and development guarantee capability (Table 1).

2.2.1. Reduction of Solid Waste. The reduction of solid waste is the primary step in the establishment of a zero-waste city. This includes taking appropriate measures to avoid and reduce resource consumption and waste generation during the process of production circulation and consumption, thereby limiting the amount of solid waste entering the final disposal process [27].

In terms of solid waste source reduction, this study selects the volume of industrial solid waste emission, the intensity of hazardous waste emission, the proportion of clean production enterprises, the intensity of construction waste emission, the quantity of ecological and circular industrial parks, the number of green agricultural development pioneer counties, the proportion of recyclable transfer bags, and the amount of domestic waste generated per capita.
as a means to evaluate the performance of the source control of solid waste generation in Shanxi province.

2.2.2. Utilization of Solid Waste. Adequate and effectual utilization of resources can minimize the emission of solid waste, as well as produce economic benefits. Therefore, improving the level of solid waste recycling and resource utilization becomes central to the construction of a zero-waste city [46]. This study selects six indicators: the comprehensive utilization rate of industrial solid waste, the utilization of industrial hazardous waste, the utilization rate of straw, the utilization rate of construction waste, the utilization rate of recyclable resources in medical institutions, and the recycling rate of domestic waste.

2.2.3. Final Disposal of Solid Waste. The solid waste disposal capacity is a determinant of the environmental impact of solid waste discharge. This study selects the safe disposal rate of industrial hazardous waste, the coverage of medical waste collection and disposal system, the disposal amount of construction waste, and the recycling and disposal levels of pesticide packaging waste; the proportion of harmless treatment of domestic waste, the ratio of public toilets to one million people, and the proportion of urban environmental cleaning areas to evaluate the capacity of safe urban waste disposal.

2.2.4. Development Guarantee Capability. The development of a zero-waste city requires an effective supporting system, such as complete sanitation infrastructure, strict environmental regulations, and the participation and support of the public in the process of solid waste management [33]. This study focuses on the number of urban environmental sanitation and cleaning equipments, the number of zero-waste city regulations and policies, the capacity for harmless treatment of solid waste, the number of permitted patent applications, investment of solid waste treatment in proportion to fiscal revenue, and public satisfaction with the performance of zero-waste city.

### Table 1: The evaluation index system of zero-waste city performance.

<table>
<thead>
<tr>
<th>Evaluation Purpose layer</th>
<th>Code layer</th>
<th>Index layer</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction of solid waste (P₁)</td>
<td></td>
<td>Intensity of industrial solid waste emission (P₁₁)</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intensity of hazardous waste emission (P₁₂)</td>
<td>—</td>
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<tr>
<td></td>
<td></td>
<td>Proportion of cleaner production enterprises (P₁₃)</td>
<td>+</td>
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<tr>
<td></td>
<td></td>
<td>Intensity of construction waste (P₁₄)</td>
<td>—</td>
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<tr>
<td></td>
<td></td>
<td>Numbers of ecological industrial Park and circular industrial park (P₁₅)</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Numbers of green agricultural development pioneer counties (P₁₆)</td>
<td>+</td>
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<tr>
<td></td>
<td></td>
<td>Proportion of recyclable transfer bags (P₁₇)</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Domestic waste emission per capita (P₁₈)</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Comprehensive utilization rate of industrial solid waste (P₂₁)</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Comprehensive utilization rate of hazardous waste (P₂₂)</td>
<td>+</td>
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<tr>
<td></td>
<td></td>
<td>Construction waste re-utilization rate (P₂₃)</td>
<td>+</td>
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<tr>
<td></td>
<td></td>
<td>Utilization rate of recyclable resources in medical institutions (P₂₄)</td>
<td>+</td>
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<tr>
<td></td>
<td></td>
<td>Recycling rate of domestic waste (P₂₅)</td>
<td>+</td>
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<tr>
<td></td>
<td></td>
<td>Safe disposal rate of industrial hazardous solid waste (P₂₆)</td>
<td>+</td>
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<tr>
<td></td>
<td></td>
<td>Coverage of collection and disposal system of medical waste (P₂₇)</td>
<td>+</td>
</tr>
<tr>
<td>Utilization of solid waste (P₂)</td>
<td></td>
<td>Disposal amount of construction waste (P₃₁)</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Recycling and disposal rate of pesticide packaging waste (P₃₂)</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Harmless treatment proportion of domestic waste (P₃₃)</td>
<td>+</td>
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<tr>
<td></td>
<td></td>
<td>Number of public toilets per million people (P₃₄)</td>
<td>+</td>
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<tr>
<td></td>
<td></td>
<td>Proportion of urban environmental cleaning areas (P₃₅)</td>
<td>+</td>
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<tr>
<td></td>
<td></td>
<td>Urban environmental sanitation and cleaning equipment numbers (P₃₆)</td>
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<td></td>
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<td>Number of operatives in environmental protection management system (P₃₇)</td>
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<td></td>
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<td>Number of zero-waste city regulation and policy (P₄₁)</td>
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<td>Harmless treatment capacity of solid waste (P₄₂)</td>
<td>+</td>
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<tr>
<td></td>
<td></td>
<td>Number of permitted patent applications (P₄₃)</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Percentage of investment into solid waste treatment in fiscal revenue (P₄₄)</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Public satisfaction with the performance of zero-waste city (P₄₅)</td>
<td>+</td>
</tr>
</tbody>
</table>
satisfaction of the performance of the zero-waste city in reflecting the "soft power" of zero-waste city construction.

2.3. Calculating Index Weight Using Entropy Weight Method. Different indicators have different influences on the performance evaluation results, which indicates their weights are different. This study uses the entropy method, an objective weighting method, to assign weights. This method is based on the analysis of the data through the decision matrix. We determine the discrete degree of index attributes. The specific steps are as follows:

1. According to the index system, we construct the original data matrix S as follows:

\[ S = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} \\ x_{21} & x_{22} & \cdots & x_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nj} \end{bmatrix} \]  

(1)

2. Index dimensional standardization

In this study, the range standardization method is used to standardize the original data. When we deal with positive indicators, the standardized calculation method is as follows:

\[ x_{ij}^\prime = \frac{x_{ij} - \min x_j}{\max x_j - \min x_j} \]

(2)

When we deal with negative indicators, the standardized calculation method is as follows:

\[ x_{ij}^\prime = \frac{\max x_j - x_{ij}}{\max x_j - \min x_j} \]

(3)

3. Normalization of index results

The standardized values were further translated to a specific range to unify the index results into a comparable area, and the translation calculation method is as follows:

\[ f_{ij} = \frac{X_{ij}}{\sum_{j=1}^{n} X_{ij}}, \quad (i = 1, 2, \ldots, m; j = 1, 2, \ldots, n). \]

(4)

4. Calculation of the entropy

\[ H_i = -k \sum_{j=1}^{n} f_{ij} \ln f_{ij}, \quad (i = 1, 2, \ldots, m; j = 1, 2, \ldots, n), \]

\[ k = \frac{1}{\ln n} \text{ when } 0 \leq H_i \leq 1; \quad \text{when } f_{ij} = 0, \quad f_{ij} \ln f_{ij} = 0. \]

(5)

5. Calculation of the index weight

\[ w_i = \frac{1 - H_i}{\sum_{i=1}^{m} (1 - H_i)} \]

(6)

where \(0 \leq w_i \leq 1, \quad \sum_{i=1}^{m} w_i = 1.\)

2.4. Comprehensive Evaluation. In this study, a comprehensive evaluation of the construction performance of a zero-waste city is carried out by the linear weighted synthesis method. The calculation formula is as follows:

\[ P = \sum W_i X_{ip} \]

(7)

where \(P\) is the evaluation score of the evaluation purpose layer, \(W_i\) is the weight of the ith indicator, and \(X_{ip}\) is the normalized value of the ith indicator. The higher the evaluation score, the higher the level of development performance of a zero-waste city.

3. Results and Discussion

3.1. Performance Level of Zero-Waste Cities in Shanxi Province. The zero-waste performance of eleven prefectural cities in Shanxi province calculated by the index system outlined in this study is shown in Table 2.

As shown in Figure 1, the typical performance of zero-waste cities in Shanxi province revealed a steady upward trend, with the average score that increased from 0.23 to 0.69.

Across eleven cities, the level of performance can be grouped into three categories: the first category is Taiyuan, the second is Changzhi, and the remaining nine cities comprise the third category. Among them, Taiyuan city's zero-waste performance level has always outclassed all the others. The overall performance level of Taiyuan city has increased exponentially of more than three times during the study period, indicating significant improvement in Taiyuan city's solid waste management. Within the third category, Lüliang city, Linfen city, Xinzhou city, and Yangquan city performed at an inferior rate in the construction of zero-waste cities.

In order to further analyze the spatial pattern of zero-waste city construction performance, this study selects four years—2010, 2013, 2016, and 2019—to analyze the spatial pattern of zero-waste city development in Shanxi province.

This study uses the natural breakpoint method to classify the evaluation results, which are divided into four levels: high (1), medium (2), low (3), and very low (4). The spatial characteristics of zero-waste city development are indicated in Figure 2.

The development level of zero-waste cities in Shanxi province has significant spatial variations, and its pattern is relatively stable, showing a trend of radial growth from Taiyuan city outward toward surrounding cities. The growth rate of zero-waste city performance in southern Shanxi was found to be faster in general than that of cities in northern Shanxi. Among them, Yuncheng city displays the most substantial improvement with regard to the level of zero-waste city construction, while Yangquan city has the smallest increase in construction performance, indicating that the industrial structure of resource-exhausted cities in combination with insufficient ecological environment management capabilities brings great challenges in achieving economic transformation and development.
3.2. Analysis of Influencing Factors. In order to further identify the main factors affecting the construction of a zero-waste city in Shanxi province, this study analyzes the evaluation results of the four subsystems of solid waste source reduction, solid waste resource utilization, solid waste final disposal, and development guarantee capability.

As depicted in Figure 3, over the course of the research period, the comprehensive score of the solid waste source reduction subsystem in Shanxi province steadily increased, with an average annual growth rate of 8.91%. The three indicators including the intensity of industrial solid waste generation, the proportion of clean production enterprises, and the number of pioneer counties for agricultural green development in Shanxi province prove to be the main factors affecting the low development rate of solid waste reduction in Luliang city, Linfen city, Xinzhou city, and Yangquan city. The reason for this is due to the high dependence on mineral resources of the districts, and the relatively lower level of urban economic development.

During the study period, the comprehensive score of the solid waste resource utilization subsystem increased from 5.77 to 9.42, a rise of 63.2% in comparison with 2010. However, the score slightly declined from 2013 to 2016, with the most significant decrease witnessed in 2014, experiencing a drop of 13.1%. The comprehensive utilization rate of industrial solid waste and industrial hazardous waste, and the recycling rate of domestic waste have all significantly decreased. In addition, the amount of domestic waste increased extensively coinciding with the acceleration of urbanization, while neither the domestic waste treatment system nor the processing capacity has been substantially improved in the short term, leading to a low utilization rate of domestic waste.

Due to the fact that Shanxi province is in a critical period of resource transformation and development, the comprehensive score of the final disposal of solid waste greatly fluctuates during the study period. Yangquan city and Shuozhou city, as typical coal resource-based cities, have the most obvious fluctuations in the safe disposal of industrial hazardous waste. From 2012 to 2016, the amount of industrial hazardous waste disposal decreased by 17.9%. The recycling and disposal rates of pesticide packaging waste in Linfen and Yuncheng reduced by 30%, mainly due to the low rate of agricultural mechanization, and the scattered agricultural pollution that cannot be centrally disposed. The coverage rate of the medical waste collection and disposal system in Shanxi province has always been at a relatively low level, lower than the medical waste treatment rate of provincial capital cities across the country, resulting in poor medical waste collection and disposal capabilities.

The overall score of the development guarantee capability subsystem in Shanxi province revealed an obvious upward trend, rising from 1.91 in 2010 to 4.55 in 2019. The upward trend is particular obvious for the indicators of harmless treatment capacity, the ratio of investment in solid waste treatment to fiscal revenue, the total number of equipment available to city sanitation, and the number of operatives in the environmental protection system. In spite of the increases in local regulations or policy documents for the construction of

<table>
<thead>
<tr>
<th>Year</th>
<th>Taiyuan</th>
<th>Changzhi</th>
<th>Yuncheng</th>
<th>Luliang</th>
<th>Jincheng</th>
<th>Linfen</th>
<th>Datong</th>
<th>Shuozhou</th>
<th>Xinzhou</th>
<th>Yangquan</th>
<th>Taiyuan</th>
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<tr>
<td>2010</td>
<td>0.30</td>
<td>0.24</td>
<td>0.14</td>
<td>0.23</td>
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<td>0.24</td>
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<td>0.15</td>
<td>0.23</td>
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<td>0.16</td>
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<td>0.34</td>
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<td>0.30</td>
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<td>0.30</td>
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<td>0.45</td>
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<td>0.29</td>
<td>0.35</td>
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<td>2014</td>
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<td>0.34</td>
<td>0.30</td>
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<td>0.47</td>
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<td>0.35</td>
<td>0.31</td>
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<td>0.41</td>
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<td>2018</td>
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<td>0.49</td>
<td>0.62</td>
<td>0.64</td>
<td>0.48</td>
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<td>2019</td>
<td>1.25</td>
<td>0.91</td>
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<td>0.64</td>
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<td>1.25</td>
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zero-waste cities in Shanxi province, the overall growth rate of local regulations shows a gradual decrease. Therefore, local governments should increase the implementation of various policies and supervision capabilities in order to improve the regional solid waste management policy system.
Further analysis of the factors affecting the performance level of waste-free city construction indicates that cities suffer the following obstructions to solid waste source reduction, resource utilization, final treatment, and development guarantee capabilities.

3.2.1. High Intensity of Industrial Solid Waste Emission against Low Comprehensive Utilization Rate. There is a close relationship between industrial structure and zero-waste city construction. Shanxi province is a typical coal resource-based region. Except for Taiyuan city, the economic development model of the remaining ten cities are dominated by its secondary industry. This is particularly true of historical industrial cities such as Changzhi, Shuozhou, Datong, and Luliang, where the generation of industrial solid waste is substantial and rapid, yet the processing capacity of industrial solid waste is relatively insufficient. This results in the low comprehensive utilization rate of industrial solid waste. In addition, due to factors such as low technical level and high recycling cost, Shanxi province has a low rate of coal clean production and utilization. The comprehensive utilization rate in 2019 was only 18.73%, which greatly restricted the comprehensive improvement of the utilization level of solid waste.

3.2.2. The Hazardous Waste Management System Needs Improvement. Hazardous waste disposal capacity is insufficient. Among the 36 hazardous waste disposal sites in Shanxi province, only 14 sites have adequate capacity for hazardous waste disposal. In addition, since sources of industrial hazardous wastes are extensive and their composition is complex, a complete supervision and information system is required. Most cities currently do not operate a standardized management of hazardous wastes; moreover, problems such as illegal dumping exist, which brings a further challenge to the construction of zero-waste cities.

3.2.3. Insufficient Capacity for Collection, Transportation, and Disposal of Medical Waste. The medical waste disposal capacity in Shanxi province does not match the production capacity, which impedes the construction of a zero-waste city. For example, the solid waste disposal centers in Changzhi city and Yuncheng city can only handle infectious and toxic wastes; Yuncheng city has the capacity only to disinfectant septic tanks to deal with the infectious waste; meanwhile, Shuozhou Medical Waste Treatment Center is only able to dispose of medical waste in nearby towns. Consequently, medical waste from some township hospitals and health centers has not been collected.

3.2.4. Low Rate of Nontoxic Disposal of Municipal Waste and Municipal Sludge. The classification of domestic waste in various cities has not been fully implemented, and as a result, traditional domestic waste landfills are overloaded. The kitchen waste in Yangquan city has not been classified and collected, and the pollution of plastic wastes in Jinzhong city is relatively significant. The construction waste in Luliang city has resulted in the waste of construction materials and land resources, and increased the cost of garbage cleaning and transportation, exacerbating the issue of groundwater pollution. The operating capacity and the safe treatment rate of Jincheng sewage and sludge are low.

4. Conclusions

This research constructs an index system for evaluating the performance of zero-waste cities in coal resource-based areas and utilizes eleven prefecture-level cities in Shanxi province as examples to carry out a comprehensive evaluation study based on the entropy weight and MCDM method.

The research results reveal significant temporal-spatial differences in the performance levels of zero-waste city construction. Within the selected time scale, the development level of zero-waste cities has been improving year by year. Notably, Taiyuan city, Yuncheng city, and Changzhi city have experienced rapid growth. Spatially, the development level of zero-waste cities gradually decreases from...
south to north and showed a radiation pattern with Taiyuan as the core.

Based on the identification of problems and the experiences from international practices, we propose several policy recommendations to improve the performance level of the zero-waste city:

4.1. Reduce Solid Waste Production at Source and Improve the Utilization Rate of Industrial Solid Waste Resources. Shanxi province should focus on resource utilization and the harmless disposal of coal industry-related waste such as coal gangue, fly ash, desulfurization gypsum, smelting slag, metal tailings, and red mud. Industrial solid waste can be reused and disposed in a safe and harmless manner. The waste management system requires improvement, and there is a requirement for the formulation of regulations for different wastes, implementation of life cycle management of solid waste, and an increase in public participation to achieve the aim of reduction of solid waste at source.

4.2. Optimize the Spatial Distribution of Regional Hazardous Waste Disposal Systems and Strengthening of Supervision of Hazardous Wastes. There is a need for comprehensive planning with regard to the utilization and disposal of hazardous wastes in Shanxi province. The risk prevention and control capabilities of hazardous wastes should be improved. Additionally, a wide range of hazardous waste disposal facilities should be established. Shanxi province should further encourage enterprises to share best practices in order to reduce and dispose hazardous wastes. Hazardous waste management units should also be combined with coal industry development to achieve coprocessing of hazardous waste.

4.3. Implement Responsible Medical Waste Disposal and Assign Supervisory Obligations to Prevent Environmental Risks. It is recommended that Shanxi province renovates and expands its medical waste treatment facilities in order to improve treatment capacity. The establishment of a supervisory structure will negate environmental sanitation risks caused by the collection, storage, transportation, and disposal of medical waste.

In accordance with the “Medical Waste Classification Catalog,” local health and medical institutions are required to classify and collect medical waste, and to transfer it to a centralized medical waste disposal site for further treatment. It is recommended that cities should introduce advanced treatment processes such as “high-temperature dry heat sterilization,” “vacuum carbonization,” “pyrolysis incineration,” and “microwave disinfection,” and further update medical waste treatment facilities as well as expand the medical waste collection system to town and village levels.

4.4. Promoting Mandatory Municipal Solid Waste Classification and Safe Disposal of Sludge. Mandatory classification and treatment of domestic waste will improve the comprehensive utilization technology of kitchen waste. Our recommendation is the construction of venous eco-industrial parks, implementation of domestic waste classification pilot projects within public institutions, communities, and rural areas, and the formation of agricultural film recycling sites and networks. Safe disposal, efficient recovery, and resource utilization technology of sludge should be promoted to ameliorate the sludge treatment and disposal level of urban sewage treatment plants.

Data Availability

The original data of the evaluation index system used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References


