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Measurement and evaluation of the comprehensive utilization efficiency of coal system industrial solid waste resources in Liupanshui City

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Abstract—Liupanshui city is located in the western part of Guizhou province, the region is extremely rich in coal resources, coal industry is more concentrated, coal mining and processing and other aspects of the solid waste resources if the good use of the city of Liupanshui city will get new development opportunities. The article takes the solid waste resources of coal industry in Liupanshui city as the research object, and uses the hierarchical analysis method to measure and evaluate the factors affecting the comprehensive utilisation of the solid waste resources of coal industry in Liupanshui city. The evaluation results show that the comprehensive utilisation of coal-based industrial solid waste resources in Liupanshui city is affected by the investment amount of solid waste per unit, technological maturity, industrial policy, and friendliness to the atmosphere. Countermeasures are proposed for these four constraints in anticipation of improving the comprehensive utilisation of coal-based industrial solid waste resources in Liupanshui city.

1. Introduction

During the "13th Five-Year Plan" period, Liupanshui City has always adhered to the treatment of bulk industrial solid waste, strictly following the principle of harmlessness and resourcefulness of industrial solid waste, reducing the production of industrial solid waste, reducing the pollution of industrial solid waste to the environment, and the comprehensive utilisation of bulk industrial solid waste in the city has been greatly improved. However, solid wastes such as coal gangue, fly ash, coal slurry and coal-fired slag produced in the process of coal mining in Liupanshui City's coal-based industry seriously damage the ecological environment of Liupanshui City, and if the coal-based industrial solid waste resources can be turned into treasures, it can, to a certain extent, promote the ecological sustainable development, and promote the parallel development of environmental governance and economic development.In 2021, Liupanshui City's production of major industrial solid wastes amounted to 29,319,900 tonnes, the comprehensive utilisation volume is 18,442,900 tonnes, and the comprehensive utilisation rate is 62.04%. Based on the existing foundation, we explore the factors affecting the comprehensive utilisation of coal-based industrial solid waste in Liupanshui City, and synergistically develop ecological sustainability.

2. Literature Review

2.1. Current status and recommendations for comprehensive utilisation of coal-based industrial solid waste resources at home and abroad

Du Genjie. [1] by studying the bulk solid waste industry in China, found that the main problems existing in the comprehensive utilization of solid waste in China are the long cycle of industrialization of the comprehensive utilization of solid waste, the imperfect product market regulatory mechanism, the lack of core technology, incomplete policies, and low capital investment.Bhatt A.[2] the utilization rate of fly ash in EU countries is as high as more than 95%, and these fly ashes are mainly utilized in building materials and road construction and other In the field of infrastructure. Tuya and Yang Lei.[3] found that the current situation of China's coal ash utilisation is characterized by unbalanced regional development, large stockpiles, backward technology, imperfect policies, and small scale of waste recycling enterprises. Ren Ruichen et al.[4] concluded that the comprehensive utilisation of tailings is another effective way to deal with the fine coal slurry, and that efficient sorting of the slurry, along with the development and utilisation of kaolin and other resources, is the most effective way to deal with fine coal slurry. The efficient separation of coal slurry and the development and use of kaolin and other resources, turning

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waste into treasure, can significantly improve the economic and social benefits of coal enterprises.Wang Ruibin.[5]showed that coal slurry is the primary product of coal enterprises, and local backward areas will make coal slurry into briquettes and activated charcoal, etc., or make coal slurry gangue into construction materials. Although this method can make the solid waste resources to achieve part of the resource, but if the coal slurry gangue is stored in large quantities, the end of the fundamental problem. The development space and potential of coal slurry combustion utilisation is huge, and one of the key ways of coal slurry resource utilisation at this stage is to enhance the added value of coal slurry. Wang Huaguo.[6] through the study of coal combustion slag analysis that it has more pores, large surface area, adsorption, activation performance, the cost is not high, such as a variety of new types of purification materials, solid waste resources coal combustion slag as a raw material for the preparation of purification materials with a high degree of feasibility. Wang Yutao.[7] pointed out through research that at the present stage of China's solid waste resources gangue comprehensive utilisation has a large number of storage and emissions, the production is extremely concentrated, the comprehensive utilisation rate is low, the development of various regions is extremely unbalanced, high value-added use of the current situation of the proportion of not high. Du Jianlei et al.[8] by analysing the reasons for the change of China's bulk industrial solid waste generation and comprehensive utilization in 2021, identified the solid waste resource value of insufficient attention, solid waste energy value is seriously constrained by the policy, cross-industry information asymmetry, the waste-producing enterprises focus on stockpiling and light utilization, the lack of diversified main market-oriented project investment model, the existence of industrial policy is homogeneous and poor landing, and so on. Wang Yingnan et al.[9] proposed that coal-fired slag can be used in the treatment of lead-contaminated wastewater as a kind of chain home and efficient adsorbent.

2.2. Research on the comprehensive utilisation of coal-based industrial solid waste resources at home and abroad

Huang Dingguo et al.[10] summarised and analysed the utilisation areas and utilisation pathways of fly ash as a solid waste resource in Japan by studying the output and utilisation volume of fly ash in Japan, which mainly include cement and concrete mixing, civil engineering, construction materials, agriculture, forestry, aquaculture, and other aspects and so on. Qiao Aiping.[11] pointed out that coal-fired slag can be used for construction, preparation of chemical raw materials, treatment of wastewater purification of water quality, soil improvement and so on. Chen Tingting.[12] found that coal mining enterprises use coal gangue to generate electricity, make building materials with low economic effect, to the Inner Mongolia Jungar use of coal gangue made of a green and environmentally friendly foamed ceramic products as an example, that its future has a broad market demand and obvious economic value. Fang Genliang.[13] in-depth discussion of the generation process of fly ash, chemical properties, composition, the use of silicate cement, ordinary silicate cement blended with fly ash method, concluded that the application of fly ash in the cement industry is the way to prepare fly ash silicate cement, fly ash ultrafine cement, composite silicate cement. Guo Yanqing.[14] found through his research that: fly ash used to make building materials is the low cost and most economical way, made into fertiliser helps to improve the soil, made into adsorbent can be used for sewage treatment. Zhu Hongzheng.[15] used mullite porous ceramics prepared from coal solid waste resources such as coal gangue and coal slurry, manipulated the particle size and addition ratio of coal slurry and wood chips to achieve the pore structure building, and after controlling the sintering temperature and adding glass powder to achieve the optimisation of the pore structure and enhanced mechanical properties. Dong Chenxi et al.[16] developed a new type of curing material using coal-based solid waste gangue, coal-based partial high territory joint arid zone easily accessible solid waste material calcium carbide slag synergistically with ordinary silicate cement.Md. Mohib-Ul-Haque Khan.[18]conducted a sensitivity analysis using Parkland County and its surrounding counties in Alberta, Canada as an example to assess the impact of key techno-economic parameters on the calculation results.Warmadewanthi I.D.A.A.[19] studied the type of biological cover (old and young refuse) and thickness (15, 20, 30 cm) as variables.The results showed that the differences of methane gas and leachate reduction in 15 vs 20 cm bio-cover thickness were significant.

In summary, domestic and foreign research on the current situation of comprehensive utilisation of coal-based industrial solid waste resources and utilisation pathways is very rich, and most scholars conclude from their research that the comprehensive utilisation of coal-based industrial solid waste resources can be applied in the fields of chemical raw materials, construction materials, agriculture, etc. Most scholars conduct research on the gangue and fly ash in power plants or take the regional coal mining industry as the object of research to study the comprehensive utilisation pathways of its solid waste resources, and there are fewer researches on the object of research and evaluation research of the solid waste resources of the coal-based industries, and there is still room for supplementation.

3. Overview of the study area

Liupanshui City is a prefecture-level city in Guizhou Province, located in the Guizhou Department, located in the Yangtze River and Pearl River Basin. At the same time, it is also the junction of four provinces or districts, namely, Sichuan, Yunnan, Guizhou and Guangxi Zhuang Autonomous Region, and has always been called "the crossroads of the four provinces", and has been included in the national "One Belt, One Road" construction and the Yangtze River Economic Belt plan, as it is one of the 66 regional circulation nodes and 196 highway traffic centre cities. It is also included in the national "Belt and Road" construction and the planning of the Yangtze River Economic Belt. Liupanshui city's traffic and location advantages are unique, relying on this good geographical location advantages, Liupanshui city vigorously develop transport, build to the public railway, water and navigation four major transport comprehensive three-dimensional transport network, for the subsequent industrial development of Liupanshui city laid the foundation of transport convenience.

In terms of resource endowment, Liupanshui City, rich in coal resources, in the country's "three lines" construction period, Liupanshui City, as a city of energy and raw materials industry gradually developed. According to statistics, Liupanshui City, coal resources amounted to 24.171 billion tonnes, ranking second in the province, with abundant reserves, coal species, quality and other characteristics, is the most huge coking coal base south of the Yangtze River, has always been "Jiangnan coal capital" title. Since the "13th Five-Year" period, Liupanshui has always been adhering to two concepts, which are "based on coal, do enough coal, not only coal" and "two-handedly, both promote", which is Liupanshui City Energy This is an all-round, deep and historic revolution in the field of energy in Liupanshui City. Various documents and policies introduced during this period have improved the industrial chain structure and promoted industrial transformation and upgrading to a certain extent, actively promoting the development of traditional coal industry to ecological development, the development of speciality coal industry to large-scale development, and the development of emerging coal industry to high-end development, and successfully obtaining the title of the second batch of national industrial transformation and upgrading pilots, which has brought Liupanshui a major strategic task and a great opportunity for development, and made its transformation and development into a brand new period.

During the "13th Five-Year Plan" period and the "14th Five-Year Plan" period, Liupanshui City has continuously increased the investment in the comprehensive utilisation of coal-based industrial solid waste, and has continued to make efforts in terms of policies, measures and platforms to optimise the development environment of the industrial solid waste utilisation industry and guide the comprehensive utilisation of coal-based industrial solid waste industry in the city. Comprehensive industrial solid waste industry to guide the city's comprehensive and healthy development; on the other hand, from the technical aspect to strengthen the development of industrial solid waste synthesis and utilisation industry, one is to strengthen the scientific and technological innovation planning, to set up a platform for the technological innovation of industrial solid waste treatment, and the second is to increase the financial investment on its scientific research, and continuously promote the comprehensive utilisation technology of coal gangue, fly ash and other industrial solid waste resources. These measures have also achieved considerable results, such as Panzhou City from the gangue in the successful extraction of titanium, iron, aluminium and other minerals, the success of the comprehensive utilization rate of the gangue to open to more than 80%, not only expand the scale of treatment of gangue, but also to make use of the technology of the high value of the breakthrough.

Generally speaking, Liupanshui City, coal-based industrial solid waste resources comprehensive utilisation progress has been fruitful, but there are still some of the more prominent problems. These problems are mainly manifested in: first, Liupanshui City, the use of coal-based industrial solid waste resources of the number of enterprises, most of the existing enterprises have a smaller scale of development, development quality and the benefits produced by the enterprise are not high, and most of them are relatively dispersed; second, most of the waste enterprises in the field of building materials industry in the low-end segment, the lack of specialised technical level and technological innovation, which also formed the majority of the Third, the city's waste enterprises have a small product market, waste enterprises have a low level of technology and equipment, the degree of integration of the "two" is not enough, and the technological content of the products is low; fourth, the city's waste enterprises and industrial solid waste emission enterprises have a low degree of coupling coordination and integration; fourth, the city's waste enterprises and industrial solid waste emission enterprises have a low degree of coupling coordination and integration. Fourthly, the degree of coordination and integration between the city's waste enterprises and industrial solid waste emission enterprises is low, the development of industrial clustering is not enough to support the city's industrial chain innovation and entrepreneurship ability is insufficient; Fifthly, the city's waste enterprises are not competitive in the market, the development of the city's waste enterprises are still experiencing operational difficulties, financing difficulties, labour difficulties, electricity costs and logistics costs are not low and other problems, the integration of the support system for innovation urgently needs to be set up, the service system needs to be perfected, the development of the environment needs to be further optimized.

4. Construction of Evaluation Indicator System for Comprehensive Utilisation of Coal-based Industrial Solid Waste Resources in Liupanshui City

4.1. Evaluation index selection basis

The author through the China Knowledge Network, Wipo database and other channels, collects industrial solid waste resources comprehensive utilisation of related literature and carried out research on the evaluation index system of the impact factors, and finally summarised the research results as shown in Table 1.

Table 1. The main research results of some scholars on the comprehensive utilisation of coal-based industrial solid waste resources and evaluation index system of influencing factors

Serial number	ArticleYear	Author	Name of the article	Reference Note
NO.1	2013	Wang qing, Chen anyan, Lan mingzhang , et al	Hierarchical analysis method for comprehensive evaluation of solid waste comprehensive utilisation technology	The article selects technical, economic, social and environmental benefits as the first-level indicators of hierarchical analysis method, and evaluates the comprehensive utilisation of industrial solid waste technology with 12 indicators as the second-level indicators, such as technological maturity, investment per unit of solid waste, operating cost per unit of solid waste, direct benefit per unit of solid waste, utilisation rate of solid waste resources, and friendliness to the weather, water environment, and soil environment.
NO.2	2014	Zhang jiansong, Huang jin, Lin ling	Research on Product Quality and Safety Evaluation Indicator System for Industrial Solid Waste Resource Utilisation	This thesis establishes a quantitative indicator evaluation system for the quality and safety of solid waste resources and products, which mainly contains four first-level indicators for energy, resources, environment and products, and 15 second-level indicators.
NO.3	2022	Wu na, Zhang xiaomin, Wu jia, et al.	Construction of Multi-dimensional Evaluation System for Solid Waste Resource Attributes in Non-ferrous Metal Industry--Tin Tailings as an Example	The paper selected six first-level indicators, including attributes such as material attributes, energy attributes and environmental attributes, and 12 second-level indicators such as solid waste generation, average income from solid waste resourcing technology, and average cost of solid waste resourcing inputs to evaluate solid waste resource utilisation in the metallurgical industry.
NO.4	2022	Qiu juanjuan, Zhai wenchao, Cui chengyue	Hierarchical analysis method for comprehensive evaluation of industrial solid waste comprehensive utilisation technology analysis	The paper uses the hierarchical analysis method to carry out a comprehensive evaluation of the comprehensive utilisation of industrial solid waste technology, which contains four first-level indicators and 12 second-level indicators in various aspects such as technology, investment, cost and environment.

4.2. Establishment of the evaluation indicator system

Referring to the main research results of the scholars in Table 1 above, the article determines that the target layer is the comprehensive utilisation of coal-based industrial solid waste resources in Liupanshui City, and the guideline layer is divided into four layers of economic benefit factors, technological factors, policy factors, and social and environmental benefit factors, with the amount of investment per unit of solid waste there is, the operating cost per unit of solid waste, the direct benefit per unit of solid waste, the added value per unit of solid waste, the maturity of technology, and the technological sophistication, Introduction of technical personnel and other 14 indicator layers. Detailed indicators as shown in Figure 1 Liupanshui City, coal-based industrial solid waste resources comprehensive utilisation impact factor evaluation index system.

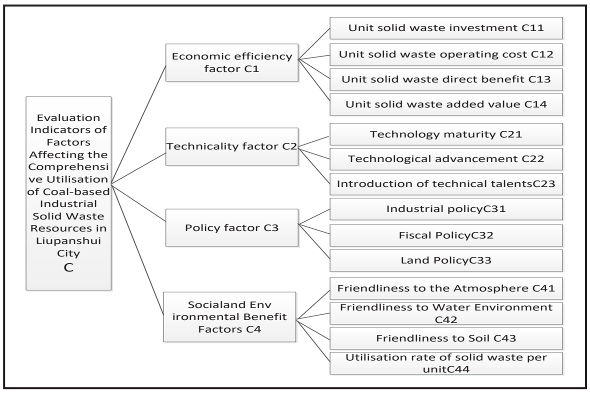

Figure 1. Evaluation index system for influencing factors of comprehensive utilisation of coal-based industrial solid waste resources in Liupanshui city

4.3. Evaluation methodology selection

4.3.1 Introduction to Hierarchical Analysis

Hierarchical analysis was introduced by Satie in 1970. This method gives priority to the organisation of complex problems, sorting out the relevant elements of the problem, and then obtaining an orderly hierarchy according to the connection between the elements, so that the complex problem can be organised. On the basis of the corresponding objective reality to make a judgement, the relative importance of each level to make quantitative expression, relying on mathematical methods to determine the relative importance of the elements of each level, and finally combined with the elements of the ranking of the specific weight of each indicator, after analysis of the results of the ranking, to find out the problem to get a solution strategy[17]. The calculation steps are as follows: the first step is to construct the hierarchical structure; the second step is to construct the judgement matrix; the third step is to calculate the relative weights and make the consistency test; the fourth step is to calculate the weight vector and make the consistency test.

4.3.2 Constructing a judgement matrix

According to the hierarchical analysis method to build the stacked order structure model, to make evaluation of the same level of related factors, the upper level of related factors as a standard, and then with the help of geometric judgement criteria to compare the two factors, so as to determine the importance of the relevant factors, and on the basis of the construction of the relevant judgement matrix. First of all, the first level of factor set U = $\{C_1, C_2, C_3\}$ =

{policy factors, technical factors, economic efficiency factors, social and environmental factors}, this paper adopts the "1-9" comparative scale method, which is a systematic analysis method proposed by Prof. Satie in 1970. The "1-9" scale method constructs a two-by-two comparison judgement matrix as shown in Table 2.

Table 2. Criteria for judgement matrices on a scale of 1-9

significance scale	hidden meaning
1	The two elements are equally important
3	Represents two elements where the former is slightly more important than the latter
5	Indicates that the former of two elements is more important than the latter
7	Indicates that the former of the two elements is more strongly important than the latter
9	Indicates that the former of the two elements is more important than the latter
2，4，6，8	denote the compromise between the above two neighbouring judgements
from the bottom (lines on a page)	Assuming that the ratio of the importance of element i to element j is aij, the ratio of the importance between element j and element i is $a_{ij} = 1/a_{ij}$

4.3.2.1 Criteria level judgement matrix for target level

In order to make our judgement matrix scientific and reasonable, we invited experts from Liupanshui Industry and Information Bureau, experts from Municipal Environmental Protection Bureau, experts from Municipal Investment Bureau, and experts from the government to make decision-making judgements, and the experts made judgement decisions on them by using their knowledge reserves, experiences and analytical judgement abilities, thus obtaining the judgement matrix in Table 3.

Table 3. Judgement matrix for level 1 indicators

target level A	B_1	B_2	B_3	B_4
B_1 Economic efficiency factors	1	2	3	5
B_2 Technical	1/2	1	2	3
B_3 Policy Factors	1/3	1/2	1	2
B_4 Social and Environmental Factors	1/5	1/3	1/2	1

In accordance with the judgement matrix in table 3, the steps for calculating the weights of the level 1 indicators are as follows:

a.The judgement matrix A of the criterion layer for the target layer:

$$A=\begin{pmatrix}1 & 2 & 3 & 5\\ 1/2 & 1 & 2 & 3\\ 1/3 & 1/2 & 1 & 2\\ 1/5 & 1/3 & 1/2 & 1\end{pmatrix}$$

b.Normalise the matrix A:

$$A=\begin{pmatrix}0.4918 & 0.5217 & 0.4615 & 0.4545\\ 0.2459 & 0.2609 & 0.3077 & 0.2727\\ 0.1639 & 0.1304 & 0.1538 & 0.1818\\ 0.0984 & 0.0870 & 0.0769 & 0.0909\end{pmatrix}$$

c.Compute the maximum eigenvector W^T:

$$W^T=\begin{pmatrix}0.4824\\ 0.2718\\ 0.1575\\ 0.0883\end{pmatrix}$$

d.Calculate the largest eigenvalue λ_{max} :

$$\lambda_{max}=4.0145$$

e.Calculate CI and CR:

RI=0.89, n=4, CI=0.0048, CR=0.0054

Since CR = 0.0054 < 0.1, that is, the judgement matrix passes the consistency test.

4.3.2.2 Judgement matrix from the indicator level to the guideline level

Similarly, the judgement matrix of the indicator level for the criterion level is constructed respectively, and the weights of the first-level indicators are calculated, and the results are shown in Tables 4 to Tables 7.

Table 4. C_{ij} for C_1 judgement matrix (j=1,2,3,4)

C_1-C_{ij}	C_{11}	C_{12}	C_{13}	C_{14}	Weighting (W_{ij})
C_{11}	1	3	2	5	0.4730
C_{12}	1/3	1	1/3	2	0.1425
C_{13}	1/2	3	1	3	0.2978
C_{14}	1/5	1/2	1/3	1	0.0867
λ_{max}=4.0651，CI=0.0217，CR=0.0244＜0.1，Passes a one-time test					

Table 5. C_{2j} for the judgement matrix of C_2 (j=1,2,3)

C_2-C_{2j}	C_{21}	C_{22}	C_{23}	Weighting (W_{ij})
C_{21}	1	3	7	0.6687
C_{22}	1/3	1	3	0.2431
C_{23}	1/7	1/3	1	0.0882
λ_{max}=3.0037，CI=0.0035，CR=0.0061＜0.1，Passes a one-time test				

Table 6. C_{3j} for C_3 judgement matrix (j=1,2,3)

C_3-C_{3j}	C_{31}	C_{32}	C_{33}	Weighting (W_{ij})
C_{31}	1	5	2	0.5813
C_{32}	1/5	1	1/3	0.1096
C_{33}	1/2	3	1	0.3092
λ_{max}=3.0037，CI=0.0018，CR=0.0032＜0.1，Passes a one-time test				

Table 7. C_{4j} for C_4 judgement matrix (j=1,2,3,4)

C_4-C_{4j}	C_{41}	C_{42}	C_{43}	C_{44}	Weighting (W_{ij})
C_{41}	1	3	5	7	0.5579
C_{42}	1/3	1	3	5	0.2633
C_{43}	1/5	1/3	1	3	0.1219
C_{44}	1/7	1/5	1/3	1	0.0569
λ_{max}=4.1185，CI=0.0237，CR=0.0266＜0.1，Passes a one-time test					

4.3.3 General ordering and one-off tests

Calculate the evaluation index of the influence factors of each indicator on the comprehensive utilisation of coal-based industrial solid waste resources in Liupanshui city in the target layer, and then carry out the total ranking, and the ranking results are shown in Table 8.

Table 8. Combined weight of each indicator in relation to the evaluation of factors affecting the comprehensive utilisation of coal-based industrial solid waste resources in Liupanshui city.

Primary Indicator	**Single sort**	**Secondary indicators**	**Single sort**	**Overall sorting**
Economic efficiency factor C_1	0.4842	Unit solid waste investment C_{11}	0.5435	0.3442
		Unit solid waste operating cost C_{12}	0.2675	0.1694
		Unit solid waste direct benefit C_{13}	0.0923	0.0585
		Unit solid waste added value C_{14}	0.0967	0.0613
Technicality factor C_2	0.2718	Technology maturity C_{21}	0.6687	0.1818
		Technological advancement C_{22}	0.2431	0.0661
		Introduction of technical talentsC_{23}	0.0882	0.0240
Policy factor C_3	0.1575	Industrial policyC_{31}	0.5813	0.1514
		Fiscal PolicyC_{32}	0.1096	0.0285
		Land PolicyC_{33}	0.3092	0.0805
Social and Environmental Benefit Factors C_4	0.0883	Friendliness to the Atmosphere C_{41}	0.5579	0.0592
		Friendliness to Water Environment C_{42}	0.2633	0.0280
		Friendliness to Soil C_{43}	0.1219	0.0129
		Utilisation rate of solid waste per unitC_{44}	0.0569	0.0060

4.3.4 Evaluation criteria

4.3.4.1 quantitative standard

In this paper, the coal-based industrial solid waste resources in Liupanshui City as a research object, to explore the degree of influence of the factors affecting the comprehensive utilisation of industrial solid waste resources, we refer to the relevant research results at home and abroad, to get a clear standard, to determine the qualitative and quantitative standards of the selected indicators into the Table 9 shows.

Table 9. Liupanshui City coal-based industrial solid waste resources comprehensive utilisation impact factor evaluation index quantitative treatment standard

Indicators	**Quantitative criteria**				
	0-2 points	**2-4 points**	**4-6 points**	**6-8 points**	**8-10 points**
Unit solid waste investment C_{11}	≤50	50-100	150-200	200-250	≥250
Unit solid waste operating cost C_{12}	≤25	25-50	50-100	100-150	≥150
Unit solid waste direct benefit C_{13}	Few	Less	Average	More	A lot
Unit solid waste added value C_{14}	Few	Less	Average	More	A lot
Technology maturity C_{21}	Very weak	Weak	Average	Stronger	Exceptionally strong
Technological advancement C_{22}	Very weak	Weak	Average	Stronger	Exceptionally strong
Introduction of technical talentsC_{23}	Few	Less	Average	More	A lot
Industrial policyC_{31}	Not supportive	Not very supportive	Fairly supportive	More Supportive	Support
Fiscal PolicyC_{32}	Not supportive	Not very supportive	Fairly supportive	More Supportive	Support
Land PolicyC_{33}	Not supportive	Not very supportive	Fairly supportive	More Supportive	Support
Friendliness to the Atmosphere C_{41}	Not good	Not so good	Fair	Better	Very good
Friendliness to Water Environment C_{42}	Not good	Not so good	Fair	Better	Very good
Friendliness to Soil C_{43}	Not good	Not so good	Fair	Better	Very good
Utilisation rate of solid waste per unitC_{44}	Very low	Low	Average	Higher	Very high

In this paper, the comprehensive index will be used to evaluate the comprehensive utilisation of coal-based industrial solid waste resources in Liupanshui city, using the formula $EI = \sum_{i=1}^{n} EI_i \times W_i$

EIi in the formula indicates the score of each index in the evaluation index system of influence factors of comprehensive utilisation of coal-based solid waste resources in Liupanshui city, and Wi represents the weight of the index.

When $0 \leq EI \leq 2$ points, it indicates that the degree of influence of comprehensive utilisation of coal-based industrial solid waste resources is weak; when $2 \leq EI \leq 4$ points, it indicates that the degree of influence of comprehensive utilisation of coal-based industrial solid waste resources is weak; $4 \leq EI \leq 6$ points, it indicates that the degree of influence of comprehensive utilisation of coal-based industrial solid waste resources is general; $6 \leq EI \leq 8$ points, it indicates that the degree of influence of comprehensive utilisation of coal-based industrial solid waste resources is strong; 8 ≤ EI ≤ 10 points, it indicates that the degree of influence of comprehensive utilisation of coal-based industrial solid waste resources is strong. EI ≤ 10 points, indicating that the comprehensive utilisation of coal-based industrial solid waste resources has a strong degree of influence.

4.3.4.2 Evaluation data and quantitative scores

This paper combines the relevant situation and data collection on the factors affecting the comprehensive use of coal-based industrial solid waste resources in Liupanshui City, analyses and calculates the indicators, and quantifies the qualitative and quantitative indicators, as shown in Table 10 below.

Table 10. Quantitative scores of evaluation indicators for impact factors of comprehensive utilisation of coal-based industrial solid waste resources in Liupanshui city

Indicator Layer	gauge	Quantitative criteria	EIi	EIi·Wi
Unit solid waste investment C_{11}	From《 the 2021 Liupanshui City Statistical Yearbook》, we know that the amount of fixed asset investment in Liupanshui in 2020 will be 197.188 billion yuan; 《The 14th Five-Year Development Plan of Liupanshui City》	≥250	6	2.0652
Unit solid waste operating cost C_{12}	《Development Plan of Liupanshui City for the 14th Five-Year Plan》	100-150	5	0.847
Unit solid waste direct benefit C_{13}	《Implementation Programme on Accelerating the Comprehensive Utilisation of Bulk Industrial Solid Waste》	usual	4	0.234
Unit solid waste added value C_{14}	《Implementation Programme of the People's Government of Liupanshui City on Accelerating the Comprehensive Utilisation of Bulk Industrial Solid Waste》	usual	5	0.3065
Technology maturity C_{21}	《Implementation Programme on Accelerating the Comprehensive Utilisation of Bulk Industrial Solid Waste》	usual	5	0.909
Technological advancement C_{22}	《Implementation Programme on Accelerating the Comprehensive Utilisation of Bulk Industrial Solid Waste》, 《Implementation Programme for the Construction of a Demonstration Base for the Comprehensive Utilisation of Bulk Solid Waste in Liupanshui City (2021-2025)》	usual	4	0.2644
Introduction of technical talentsC_{23}	《Measures for the Introduction of High-level Talents in Liupanshui City》, 《Service Guidelines for High-level Talents in Liupanshui City》	usual	5	0.12
Industrial policyC_{31}	《Planning for the Comprehensive Utilisation of Coal-based Solid Waste in Liupanshui City》	General Support	6	0.9084
Fiscal PolicyC_{32}	《Programme for the Implementation of the "Reform of Hundreds of Enterprises Project to Promote Industrial Transformation and Upgrading in Liupanshui City》《the Implementation Programme on Accelerating the Comprehensive Utilisation of Bulk Industrial Solid Wastes》	General Support	5	0.1425
Land PolicyC_{33}	《Programme for the Implementation of the "Reform of Hundreds of Enterprises Project to Promote Industrial Transformation and Upgrading in Liupanshui City》《 the Implementation Programme on Accelerating the Comprehensive Utilisation of Bulk Industrial Solid Wastes》	General Support	4	0.322
Friendliness to the Atmosphere C_{41}	《Implementation Programme on Accelerating the Comprehensive Utilisation of Bulk Industrial Solid Waste》	usual	6	0.3552
Friendliness to Water Environment C_{42}	《Implementation Programme on Accelerating the Comprehensive Utilisation of Bulk Industrial Solid Waste》	usual	5	0.14
Friendliness to Soil C_{43}	《Implementation Programme on Accelerating the Comprehensive Utilisation of Bulk Industrial Solid Waste》	preferably	6	0.0774
Utilisation rate of solid waste per unitC_{44}	《The 14th Five-Year Plan for the Development of Industry in Liupanshui City》	preferably	6	0.036

4.3.4.3 Discussion of evaluation findings

According to the quantitative score of the evaluation index of comprehensive utilization of industrial solid waste resources in Liupanshui coal system in Table 10, the score of each index will be calculated and analysed and the evaluation results will be analysed. The economic efficiency factor index scores 3.4527 points, and the constraints are added value per unit of solid waste and direct benefit per unit of solid waste; the technical factor index scores 1.2934 points, and the constraints are technological sophistication and introduction of technical talents; the policy factor index scores 1.3729 points, and the constraints are financial and tax policies; the social and environmental efficiency factor index scores 0.6086 points, and the constraints are the degree of friendliness to the soil and the unit solid waste utilisation rate; the comprehensive evaluation index scored 6.7276 points. It can be seen that the economic benefit factor is the main factor affecting the comprehensive utilisation of coal-based industrial solid waste resources in Liupanshui City, followed by policy and technical factors, and the social and environmental benefit factor has the least influence. From the evaluation results of the secondary factors in Table 8, it can be seen that from the perspective of economic efficiency factors, the influence of unit solid waste investment amount factors is the largest, and the influence of unit solid waste direct benefit factors is the smallest; from the perspective of technical factors, the influence of technical maturity factors is larger, and the influence of introducing technical talents factors is the smallest; from the perspective of policy factors, the influence of industrial policy factors is the largest, and the influence of fiscal policy factors is the smallest; from the perspective of social and environmental benefits, the influence of social and environmental benefits factors is the largest. From the perspective of social and environmental benefits, the factors of atmospheric friendliness have the greatest impact, and the factors of unit solid waste utilisation have the least impact. Thus, it is known that the investment amount of solid waste per unit, the maturity of technology, industrial policy, and the friendliness to the atmosphere are the key factors affecting the comprehensive utilisation of coal-based industrial solid waste resources in Liupanshui city. From the analysis, it can be seen that the quantitative score of the evaluation of factors affecting the comprehensive utilisation of coal-based industrial solid waste resources in Liupanshui city is 6.7276, which belongs to the category of good development.

5. Conclusions

The study shows that the comprehensive utilisation of coal-based industrial solid waste resources in Liupanshui city belongs to the category of good development, with a better development foundation and greater development prospects. Among the influencing factors of the comprehensive utilisation of coal-based industrial solid waste resources, the economic benefit factor is the most important factor affecting the efficiency of the comprehensive utilisation of coal-based industrial solid waste resources in Liupanshui City, followed by the policy and technical factors, and the social and environmental benefit factors have the least influence. Among the secondary indicators, unit solid waste investment amount, technology maturity, industrial policy, and friendliness to the atmosphere are the key factors affecting the comprehensive utilisation of coal-based industrial solid waste resources in Liupanshui city. There are the following suggestions for this:

5.1. Build a multi-faceted investment and financing system to enhance financial security

The government of Liupanshui City should actively apply for more special funds from the national or provincial level, and increase the financial support for the comprehensive utilisation of solid waste resources in the coal industry, to solve the problem of shortage of funds for enterprises and to ensure the normal operation of these enterprises. Can be created through the development of solid waste resources comprehensive utilisation of development guidance fund, to lead the social capital investment to the comprehensive utilisation of solid waste resources enterprises; improve the financial support for the comprehensive utilisation of solid waste resources enterprise development system, improve the capital turnover system; to promote the green solid waste resources utilisation of enterprise project financing library construction, improve the financial system, increase the supply of financial resources, enhance the security of funds.

5.2. Improve the maturity of technology and promote the comprehensive utilisation of solid waste resources in the coal industry

On the basis of these achievements in the "13th Five-Year Plan" period, the Liupanshui municipal government should unite colleges and universities and scientific research institutes, take the road of cooperation between industry, academia and research institutes, and continue to research and forge ahead to overcome the bottleneck technology limiting the comprehensive utilisation of industrial solid waste of the coal system in Liupanshui city, improve the maturity of the technology, promote the comprehensive utilisation of solid waste resources in Liupanshui, and accelerate the "waste to treasure". "Waste to treasure". The improvement of technical maturity is inseparable from technical personnel, Liupanshui City, according to the needs of the comprehensive utilisation of coal-based industrial solid waste resources enterprises, and actively introduce various types of high-level technical personnel, innovative technology teams, scientific research teams, etc., to grow the original talent team of Liupanshui City, solid waste enterprises, to improve the level of scientific and technological innovation, and provide technical support for the comprehensive utilisation of coal-based industrial solid waste resources technology.

5.3. Strengthen policy propaganda, strengthen the implementation of industrial policy

Meticulous practice of national resources comprehensive utilisation of the relevant superior policies, the state actively incentivise the enterprise itself to carry out the evaluation of the comprehensive utilisation of solid waste resources of the enterprise, encourage eligible enterprises to declare the tax reduction and exemption preferential policies, encourage the research and development of new products of the comprehensive utilisation of solid waste resources, the development and promotion of new technologies and technological improvements, key demonstration project construction. In addition to this, the Liupanshui municipal government can also introduce corresponding tax incentives and reward policies. In the tax aspect of tax reduction and tax cuts, improve the coal industry solid waste resources comprehensive utilisation enterprises live, in the policy support, the industrial revitalisation; in the reward aspect, if the enterprise can deal with the relationship between the solid waste in the environment, for example, piles of solid waste resources occupies an area of small, then the rewards for this type of enterprise, in fact, it is a kind of investment in the comprehensive utilisation of solid waste resources enterprises.

5.4. Promote the green transformation of solid waste utilisation and build a healthy ecological environment

The government should encourage the comprehensive utilisation of solid waste resources enterprises to actively carry out their own green manufacturing production and comprehensive utilisation of solid waste resources and other evaluations, and promote the implementation of standardised management of key solid waste resources utilisation and comprehensive utilisation enterprises, and actively participate in the creation of national as well as provincial-level green factories, green development of products and green industrial parks, and promote the development of the comprehensive utilisation of solid waste resources of the coal system industry in Liupanshui City, and build a healthy ecological environment.

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