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Research on the Evaluation of Waste Home Appliance Recycling Mode Based on Combination Weighting Cloud Model

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***Abstract**: In order to more accurately evaluate the recycling mode of waste household appliances in enterprises, combined with previous experience, a combined weighting cloud model evaluation method is used to explore the operational effectiveness of the recycling mode of waste household appliances. Firstly, based on previous research, establish an evaluation index system for the recycling mode of waste household appliances. Then G1 and entropy weight methods are used for subjective and objective weighting, and the combined weights are determined based on Lagrange's theorem. Finally, by generating evaluation standard cloud maps and comprehensive evaluation cloud maps, taking H Company as an example, the cloud maps are compared. The results indicate that the overall operational level of H Company's waste home appliance recycling model is good, but the technical capacity, enterprise management capacity, and environmental protection capacity still need to be further improved. The evaluation results are consistent with reality, and the evaluation method is feasible.*

***Keywords**: Combination weighting-Cloud model, waste household appliances, recycling mode*

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I. Introduction

In 2021, the National Development and Reform Commission of China released the “Implementation Plan for Improving the Recycling and Treatment System of Waste Household Appliances and Promoting the Consumption of Household Appliances Renewal”, proposing key tasks such as further improving the recycling and treatment system of waste household appliances and promoting the consumption of household appliances renewal. Jiang and Wu **Error! Reference source not found.** summarized four typical recycling models based on the different participants in reverse logistics recycling, and proposed an evaluation index system for the key factors affecting the selection of recycling models. Gonget al. **Error! Reference source not found.** analyzed and identified the factors that affect the selection of recycling modes in the reverse supply chain. Exploratory factor analysis was used to identify the main factors and construct an evaluation index system for recycling modes. Liet al. **Error! Reference source not found.** combined the actual situation of household appliance recycling behavior at home and abroad, obtained five main factors that affect residents' willingness to recycle behavior through a survey questionnaire, analyzed the degree of impact, and proposed a conceptual model. Starting from the current status of waste electrical appliance recycling technology and equipment, Du **Error! Reference source not found.** proposes an evaluation model for evaluating the utilization standards of WEEE recycling resources for all life cycles of WEEE.

II. Construction of evaluation index system for recycling mode of waste household appliances

According to materials such as the "Waste Electrical Appliances Recycling and Treatment System and Management Mechanism" and the "Waste Electrical Appliances and Electronic Products Recycling Specification", it can be seen that the recycling mode of waste electrical appliances is generally influenced by several factors such as economy, technological level, enterprise management, environmental protection, and social services. In the process of writing this article, the author combines the actual situation and constructs an evaluation system for the recycling mode of waste household appliances based on the research of Gong et al.

and Jiang et al. evaluation index systems. The evaluation index system is composed of five parts: economy, technology, management, environmental protection, and social service. Each part is composed of several specific indicators, and the specific evaluation index system is shown in Figure 1.

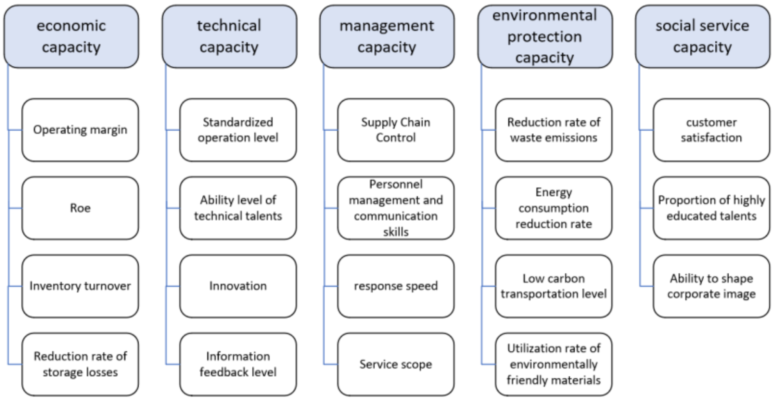

Figure 1 Evaluation system for recycling mode of waste household appliances

2 Research on the Evaluation Model of Recycling Mode

2.1 Determination of evaluation index weights

2.1.1 G1 order relationship analysis method for subjective weighting

Determine subjective weights using the G1 order relationship analysis method. The Index set P (P1, P2, P3,..., Pn) is composed of multiple indicators, and industry experts are invited to select the most important indicators in the Index set P in turn according to their experience to obtain the ranking of the importance of each indicator **Error! Reference source not found.**. Determine the importance ratio of adjacent indicators $w_1/w_2=r_2$, and assign r using the index scale in Table 1. After determining all index scales, calculate the indicator weights using the following formulas:

$$w1_j = \frac{1}{(1+\sum_{j=2}^{n}\prod_{i=j}^{n} r_i)} \tag{1}$$

$$w1_{j-1} = r_j w1_j, (j = n, n-1, ..., 2) \tag{2}$$

Table 1 Assignment reference

r_k assignment	Assignment Meaning
1	X_{k-1} is equally important as X_k
1.2	X_{k-1} is slightly more important than X_k
1.4	X_{k-1} is significantly more important than X_k
1.6	X_{k-1} is more important than X_k
1.8	X_{k-1} is extremely important than X_k
1.1,1.3,1.5,1.7	Between two adjacent degrees

2.1.2 Objective weighting using entropy weight method

Determine objective weights using entropy weight method. Invite experts to quantitatively assign values to the evaluation indicators. If there are m evaluation objects and n evaluation indicators, the original data matrix can be formed. Standardize it to get the normalized matrix $R = (r_{qj})_{mn}$, r_{qj} is the assignment of the *j*-th indicator in the *q*-th project. Then calculate according to the following steps **Error! Reference source not found.**.

(1) Calculate the proportion of the *j*-th indicator value in the *q*-th project

$$P_{qj} = \frac{r_{qj}}{\sum_{q=1}^{m} r_{qj}} \tag{3}$$

(2) Calculate the entropy value of the *j*-th indicator

$$e_j = -k\sum^{m} r_{qj} \cdot \ln P_{qj}, k = \frac{1}{\ln m} \tag{4}$$

(3) Calculate the entropy weight of the *j*-th indicator

$$w2_j = \frac{(1-e_j)}{\sum_{j=1}^{n}(1-e_j)} \quad (5)$$

2.1.3 Determination of Combination Weights

In this paper, the G1 order relationship analysis method is used to determine the subjective weight, and the entropy weight method is used to determine the objective weight. According to the minimum information entropy principle after the optimization of Lagrange multiplication, the following formula is used to calculate the combined weight value **Error! Reference source not found.**:

$$w_j = \frac{\sqrt{w1_j w2_j}}{\sum_{j=1}^{n} w1_j w2_j} \quad (6)$$

2.2 Cloud Model Evaluation

2.2.1 Cloud Model Theory

Cloud models can transform qualitative concepts into quantitative data, transforming uncertain language into quantitative analysis. The eigenvalues of the cloud model are composed of three characteristic parameters: expected value Ex, entropy En, and hyper-entropy He. In cloud model theory, each x in the quantitative domain U is called a cloud droplet, which is a random implementation of the qualitative concept C (Ex, En, He) in U. The degree of certainty of x for C is u (x), where u (x)$\in$[0.1]. In the quantitative domain U, the set of uncertainties of multiple quantitative values corresponding to C is called a cloud. Expecting Ex to reflect a qualitative concept, which is the center of gravity of the cloud droplet group. Entropy reflects the Statistical dispersion, randomness and fuzziness of cloud droplets. Hyper-entropy is a measure of the degree of entropy uncertainty, reflecting the degree of condensation of cloud droplets.

The cloud model uses a cloud generator as a tool to transform qualitative and quantitative concepts, converting digital feature values into cloud droplets. The forward cloud generator converts qualitative concepts into quantitative values, while the reverse cloud generator converts quantitative values into qualitative concepts. This article uses a reverse cloud generator to invite n experts to score each secondary indicator and obtain the cloud digital feature values of the indicators. The specific algorithm is as follows:

$$Ex = \frac{1}{n}\sum_{j=1}^{n} x_j \quad (7)$$

$$En = \sqrt{\frac{\pi}{2}} \cdot \frac{1}{n}\sum_{j=1}^{n} \left| x_j - Ex \right| \quad (8)$$

$$He = \sqrt{\left| S^2 - En^2 \right|} \quad (9)$$

$$S^2 = \frac{1}{n-1}\sum_{j=1}^{n} \left(x_j - Ex \right)^2 \quad (10)$$

2.2.2 Standard evaluation Cloud

This article uses the golden section method to determine the digital feature values of the standard comment cloud in the domain [0,1], draws a standard cloud map, and divides the operation level of the waste home appliance recycling mode into five levels: I (Very poor), II (Relatively poor), III (Generally good), IV (Relatively good), and V (Extremely good). The characteristic values of the evaluation criteria cloud are shown in Table 2, and the drawn evaluation criteria cloud map is shown in Figure 2.

Table 2 Standard cloud digital feature values

Cloud digital feature values	Ex	En	He
I (Very poor)	0	0.103	0.013
II (Relatively poor)	0.309	0.064	0.008
III (Generally good)	0.5	0.039	0.005
IV (Relatively good)	0.691	0.064	0.008
V (Extremely good)	1	0.103	0.013

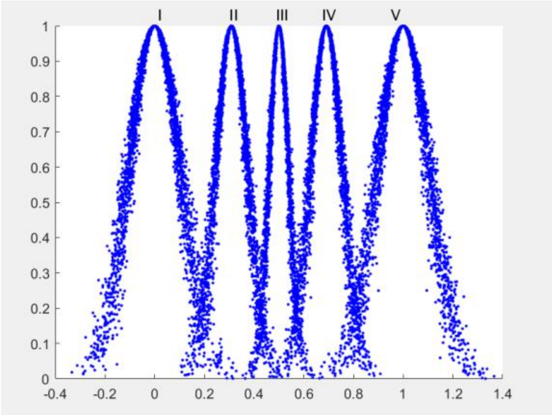

Figure 2 Standard evaluation cloud

2.2.3 Comprehensive Cloud evaluation for recycling mode of waste home appliances

By combining weights, the cloud digital feature values of the first level indicator are calculated based on the cloud parameters of the second level indicator. Then, the comprehensive cloud parameters are obtained by combining the weights of the first level indicator (see equations 11-13) **Error! Reference source not found.**. The comprehensive evaluation cloud of the waste household appliance recycling mode obtained is compared with the standard evaluation cloud on one cloud map, and the evaluation conclusion is drawn.

$$Ex^* = \frac{1}{\sum_{j=1}^{n} w_j} \sum_{j=1}^{n} Exw_j \tag{11}$$

$$En^* = \frac{1}{\sum_{j=1}^{n} {w_j}^2} \sum_{j=1}^{n} {w_j}^2 En \tag{12}$$

$$He^* = \frac{1}{\sum_{j=1}^{n} {w_j}^2} \sum_{j=1}^{n} {w_j}^2 He \tag{13}$$

III. Example Analysis

H Company is a domestic manufacturer of household appliances that responds to the extended producer responsibility system to carry out household appliance recycling business. This article takes H Company as an example to evaluate its current household appliance recycling model, which has guiding significance for other domestic enterprises in the same industry.

3.1 Calculation of Weights for Combination Weighting

First of all, 10 experts in the electronic and electrical recycling industry were invited to compare and rank the importance of indicators in pairs based on their own experience. Taking the economic capacity, technical capacity, management capacity, environmental protection capacity, and social service capacity of the first level indicators as an example, set the first level indicator set as M (A1, A2, A3, A4, A5), statistically sort out the expert opinions, and get the order relationship: A1>A3>A2>A5>A4. According to the index scale in Table 1, the subjective weight of the first level indicators can be calculated in combination with Formulas (1-2). Similarly, repeating the same steps can obtain the subjective weight values of the secondary indicators. After the subjective weight value w1 of all indicators is obtained according to the above steps, the above 10 experts are asked to score the indicators in a 5-point system according to the Likert scale method. The objective weight w2 of the evaluation indicators is obtained according to Formulas (3-5), and the subjective and objective weight is substituted into Formula (6) for calculation to obtain the combined weight. The results are shown in Table 3.

Table 3 Evaluation index weight value

the first level indicator	G1 method	Entropy weight method	combined weight	the second level indicator	G1 method	Entropy weight method	combined weight
A1	0.302	0.072	0.187	A11	0.339	0.12	0.043
				A12	0.339	0.274	0.065
				A13	0.212	0.519	0.071
				A14	0.193	0.088	0.028
A2	0.232	0.469	0.3505	A21	0.328	0.544	0.09
				A22	0.252	0.128	0.038
				A23	0.21	0.123	0.034
				A24	0.21	0.204	0.044
A3	0.166	0.241	0.2035	A31	0.348	0.339	0.073
				A32	0.29	0.46	0.078
				A33	0.193	0.092	0.028
				A34	0.175	0.109	0.029
A4	0.166	0.111	0.1385	A41	0.299	0.092	0.035
				A42	0.249	0.005	0.008
				A43	0.226	0.31	0.056
				A44	0.226	0.593	0.078
A5	0.138	0.107	0.1225	A51	0.404	0.74	0.117
				A52	0.311	0.147	0.046
				A53	0.283	0.113	0.038

3.2 Evaluation and analysis of recycling mode

3.2.1 Computing of cloud models

This article calculates qualitative indicator cloud models and quantitative indicator cloud models based on the different properties of indicators. Then, the comprehensive evaluation cloud of indicators is calculated based on the comprehensive cloud algorithm, and finally compared with the standard evaluation cloud of indicators. The evaluation indicators studied include ten qualitative indicators, including technical talent ability level, innovation level, personnel management and communication skills. The above 10 industry related experts are invited to quantitatively score the qualitative indicators within the 0-1 range, and calculate the cloud digital characteristic values of the qualitative indicators according to equations (7-10). Then, collect the financial statement data of the enterprise and other real data provided by the enterprise's official website. After the quantitative data is dimensionless, the cloud digital characteristic values of quantitative indicators such as operating profit rate, return on net assets, and Inventory turnover rate are also calculated.

Summarize the cloud models of all secondary indicators, as shown in Table 4.

Table 4 Secondary indicator evaluation cloud parameters

the second level indicator	cloud parameters(Ex, En, He)
A11	(0.5981,0.0082,0.0010)
A12	(0.6564,0.0716,0.0210)
A13	(0.6418,0.0595,0.0107)
A14	(0.5528,0.0186,0.0059)
A21	(0.5740,0.0511,0.0269)
A22	(0.5200,0.0577,0.0192)
A23	(0.5010,0.0566,0.0170)
A24	(0.4410,0.0509,0.0294)
A31	(0.6130,0.0905,0.0167)
A32	(0.5370,0.0840,0.0127)
A33	(0.4820,0.0727,0.0157)
A34	(0.4530,0.0722,0.0111)
A41	(0.5689,0.0074,0.0048)
A42	(0.6133,0.0376,0.0121)
A43	(0.4510,0.0494,0.0062)
A44	(0.6000,0.0388,0.0122)
A51	(0.8411,0.0721,0.0103)
A52	(0.7621,0.0476,0.0182)
A53	(0.4150,0.0426,0.0074)

According to equations (11-13), combined with the combination weights calculated in the previous text, the first level index evaluation cloud parameters and comprehensive evaluation cloud parameters are obtained, and the cloud map is drawn using MATLAB software.

3.2.2 Cloud model evaluation analysis

From the comparison between the first level indicator evaluation cloud map and the standard evaluation cloud map in Figure 3, it can be seen that the economic capacity of Company H is between "III (Generally good)" and "IV (Relatively good)", the technical capacity, enterprise management capacity, and environmental protection capacity are close to "III (Generally good)", and the social service capacity is between "IV (Relatively good)" and "V (Extremely good)". This indicates that H Company needs to improve its technical capabilities, strengthen enterprise management, and focus on environmental protection in its future development.

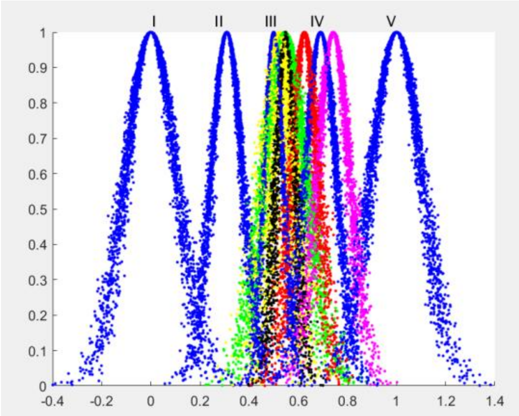

Figure 3 Primary indicator evaluation Cloud

From the comprehensive evaluation cloud map shown in Figure 4, it can be seen that the operational level of H enterprise's waste home appliance recycling model is between "III (Generally good)" and "IV (Relatively good)", indicating that there is still great room for improvement in this recycling model.

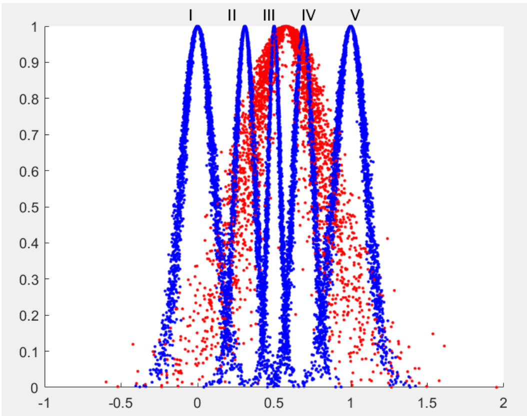

Figure 4 Comprehensive evaluation Cloud

IV. Conclusion

In order to better and more accurately evaluate the enterprise's home appliance recycling model, this article uses G1 order relationship analysis and entropy weight method, combined with subjective and objective weights to assign indicator weights. Cloud models are used to express problems with uncertainty, and intuitive cloud maps are used for evaluation, improving the credibility of the evaluation. Through the analysis of cloud maps, the weaknesses of enterprise capabilities in the recycling model were identified, and the feasibility of the evaluation method was verified.

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