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COMBINATION WEIGHTING-UNASCERTAINED MEASUREMENT MODEL OF GREEN MINING ECOLOGICAL MINE CONSTRUCTION

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Abstract. *Scientifically evaluating the green mining ecological mine construction result plays an important guiding role to green mining ecological mine construction in the future. According to the characteristics of the green mining ecological mine construction, the paper establishes an evaluation index system, from the 6 aspects of resource consumption, resource utilization, pollution emissions, advanced technology, ecological restoration and carbon management. The paper determines the combined weights by using the preference coefficient method determined by precedence chart and information entropy, and then establishes an evaluation model by using combination weighting-unascertained measurement method. Finally, the paper evaluates the three national level green mining pilot units of Jizhong Energy Handan Mining Group comprehensively by using this model.*
Keywords: Green mining ecological mine, Combination weighting, Unascertained measurement

1. **Introduction.** National Mineral Resource Planning (2008-2015) and The Guidance of the Implementation of National Mineral Resources Planning and the Development of Green Building Green Mines Mining Work (Ministry of Land and Resources issued [2010] No. 119) determined the strategic target of the general establishment about green mine pattern in 2020. The coal mining theory requires that during the process of coal mining, we should regard not only coal but also atmosphere, land, groundwater, surrounding environment, etc., as important resources, which make up the environmental ecology. And they should be developed scientifically and utilized comprehensively. In addition, mining geomorphology, human environment, ecological environment, resource environment and technical and economic environment should link to each other. And at the end of mining activities, the mine should be made to be engineering and ecological integration through the minimum end treatment. Jizhong Energy first proposed the new concept of low-carbon ecological mining that has important guiding significance for the healthy, harmonious and sustainable development of coal industry [1]. J. G. Liu explored the low-carbon ecological mining construction model and evaluation index system according to analyzing the disturbance influence of coal mining on ecological environment [2]. C. H. Xin et al. established a multi-stage comprehensive evaluation model of the low-carbon ecological mining construction evaluation, considering three dimensions: the past, present and future, through analyzing the particularity of the low-carbon ecological mining construction evaluation [3]. According to the present research results, some achievements about the evaluation of green mining ecological mine construction have been obtained. However, most of researches focused on the technical level, which cannot meet the requirements of green mining ecological mine construction.

2. Evaluation Index System Construction of Green Mining Ecological Mine.

2.1. Principles of index selection and features of evaluation indicator system.

Green mining ecological mine construction needs the unremitting efforts of the whole society, the national policy supports, and the active cooperation of enterprises. It has an important guiding significance to construct a scientific and reasonable evaluation index system for green mine construction in the future.

The evaluation index system is the foundation of evaluating the effectiveness of green mining ecological mine construction, and should follow the principles of being scientific, qualitative and quantitative, systematic and level, and operational.

2.2. Constitution of evaluation indicator system.

The evaluation index system of green mining ecological mine construction is composed by 6 first-rank evaluation indexes which are resources consumption, resource utilization, pollution emission, advanced technology, ecological restoration, low carbon management, and 24 second-rank evaluation indexes, as shown in Table 1.

Table 1. Green mining ecological mine construction evaluation index

Target layer	One class index	Secondary index	Index properties
Green mining ecological mine construction evaluation index	Resource-consumption	the overall energy consumption of coal per ton (kgce/t)	qualitative
		the overall power consumption of coal per ton (kwh/t)	qualitative
		comprehensive energy consumption per unit of GDP (kgce/Ten thousand yuan)	qualitative
	Resource-utilization	gangue utilization (%)	qualitative
		raw coal washing rate (%)	qualitative
		gas utilization (%)	qualitative
		mine water utilization (%)	qualitative
	Pollution emission	SO_2 emission (t)	qualitative
		CO_2 emission (t)	qualitative
		COD emission (t)	qualitative
		solid waste emission (t)	qualitative
	Advanced technology	"three unders" mining rate (%)	qualitative
		air source heat pump and water source heat pump utilization (%)	qualitative
		water conservation mining rate (%)	qualitative
		gas extraction rate (%)	qualitative
		gob-side entry retaining rate and gob-side entry driving rate (%)	qualitative
		energy-saving equipment selection rate (%)	qualitative
	Ecological restoration	land reclamation rate (%)	qualitative
		mining area greening rate (%)	qualitative
		waste dump governance rate (%)	qualitative
	Low-carbon management	corporate culture concept of low-carbon	qualitative
		low carbon management rules and regulations	qualitative
		employees low-carbon technologies training	qualitative
		community satisfaction	qualitative

3. Combination Weighting-Unascertained Measurement Model Construction of Green Mining Ecological Mine Construction. The unascertained theory and method has been widely and successfully applied to some fields [4,5] and is made by using the combination weighting-unascertained measurement model.

Suppose X is the research object space and $X = \{x_1, x_2, x_3, \ldots, x_n\}$. x_i represents the i-th unevaluated mine and each x_i has m indicators, which is denoted as $I = \{I_1, I_2, \ldots, I_m\}$. Let x_{ij} denote the observation of x_i under I_j, let $C = \{c_1, c_2, \ldots, c_k\}$ be the evaluation space, and c_k $(1 \leq k \leq K)$ is the k-th comment rate. It is the ordered classification of evaluation space.

3.1. Single index identification. The difference about x_{ij} of x_i under I_j, will lead to the difference about each degree level review of x_i; let $u_{ijk} = u\left(x_{ij} \in c_k\right)$ represent the membership degree of x_i on I_j in the k-th grade. u_{ijk} is a measure result of the extent, which should meet the three principles of measure. And the three principles of measure are nonnegative boundedness, additivity and normalization. Then the recognition matrix of unascertained measure under the single index is shown as:

$$u_i = \left(u_{ijk}\right)_{m\times k} = \begin{bmatrix} u_{i11} & u_{i12} & \cdots & u_{i1k} \\ u_{i21} & u & \cdots & u_{i2k} \\ \vdots & \vdots & \ddots & \vdots \\ u_{im1} & u_{im2} & \cdots & u_{imk} \end{bmatrix} \quad (i = 1, 2, \ldots, n) \tag{1}$$

3.2. Combination weighting method to determine the index weight.

(1) Precedence chart. Precedence chart was first put forward by P. E. Moody in 1983. Suppose n is the number of the comparative objects, and precedence chart is a checkerboard of schemata with $n \times n$ spaces. 1 or 0 was selected to represent which is better or superior in a pairwise comparison. "1" represents the one which is "bigger", "superior" or "more important" in a pairwise comparison, while "0" represents the one which is "smaller", "inferior" or "the less important".

The weight calculation method of the precedence chart which meets the satisfaction of the complementary test is to sum the figures in each grid on horizontal rows. Then make them divided by the total number T to get the weight of each indicator respectively. The value of T is calculated as: $T = n(n-1)/2$. The blank form of precedence chart is shown as Figure 1.

	P_1	P_2	P_3	$\cdots$
P_1	-	1	0	
P_2	0	-	0.5	
P_3	1	0.5	-	
$\cdots$				-

Figure 1. Blank form of precedence chart

(2) Entropy method. Entropy method is an objective valuation method, which determines the index weight depending on the amount of information contained in each index. And the method avoids subjective and arbitrariness. The concept of information entropy is used to define the index I_j's weights.

Suppose the information entropy is determined by the measure u_{ijk} as the following.

$$H(j) = -\sum_{k=1}^{k} u_{ijk} \cdot \log u_{ijk} \tag{2}$$

Make

$$V_j^i = 1 - \frac{1}{\log k} H(j) = 1 + \frac{1}{\log k} \sum_{k=1}^{k} u_{ijk} \cdot \log u_{ijk} \tag{3}$$

And w_{ij} represents the classification weight of the I_j on x_i.

Make

$$\theta_j^i = \frac{V_j^i}{\sum_{j=1}^{m} V_j^i} \quad \left(0 \leq \theta_j^i \leq 1,\ \sum_{j=1}^{m} V_j^i = 1\right) \tag{4}$$

The attribute set I represents the weight vector.

(3) Preference coefficient method to determine the index weight. The actual weight is a comprehensive reflection of the subjective judgment of the evaluator and the objective information of the evaluation indexes. By using the weighted linear combination, the actual weight W^i can be determined by the following:

$$W^i = \mu\alpha_j + (1-\mu)\beta_j \tag{5}$$

α_j and β_j respectively represent the subjective weight (precedence chart) and the objective weight (entropy) of the j-th evaluation index; μ $(0 < \mu < 1)$ is the weight preference coefficient.

3.3. **Comprehensive evaluation system.** According to the single index matrix μ^i and the weight vector W^i, the unascertained measuring recognition vector of some sample x_i under m indicators can be calculated by the following:

$$\mu^i = (\mu_{i1}, \mu_{i2}, \ldots, \mu_{ik}) \tag{6}$$

Among them,

$$\mu^i = W^i \cdot (\mu_{ijk})_{m\times k} = \left(w_1^j, w_2^j, \ldots, w_m^j\right) \begin{bmatrix} u_{i11} & u_{i12} & \cdots & u_{i1k} \\ u_{i21} & u & \cdots & u_{i2k} \\ \vdots & \vdots & \ddots & \vdots \\ u_{im1} & u_{im2} & \cdots & u_{imk} \end{bmatrix} \tag{7}$$

3.4. **Sample identification and sorting.** The credible degree criteria should be taken, because the evaluation grades are ordered partition. The reliability is set as λ $(\lambda > 0.5)$, which usually takes 0.6 or 0.7.

Make

$$k_0 = \min_k \left[\left(\sum_{l=1}^{K} \mu_{il}\right) \geq \lambda\right] \qquad K = 1, 2, \ldots, k \tag{8}$$

Then x_i belonging to the k-th evaluation grade can be determined.

In order to rank each mine x_i studied, the scoring criteria can be used.

$$q_{x_i} = \sum_{l=1}^{K} n_k \mu_{il} \tag{9}$$

And make $n_k = 5 - k$.

4. **Empirical Researches.** In this paper, the TY, TE, YJL's declaration of the national level green mining pilot units is taken as an opportunity. And the three coal mines are taken as research objects to survey. During the evaluation of the low carbon ecological mine construction, the indexes which cannot be quantified are qualitative indexes or soft indexes. The evaluation values of the soft indexes can be obtained by using expert evaluation method and questionnaire method. According to the above index system, the comment space is {very good, good, general, and poor}, which is determined by the experts' scoring. There are twenty-four evaluation indexes. Each expert only can give

each index 10 points at most and these 10 points should distribute to four evaluation levels. Then the scoring rates of each index can be got. The scoring criterion is fairness and justness, which accords with the principles of measure.

The standard of each level is determined after the levels are set up. And these standards are obtained from the foundation of the researches on the study achievements of relevant scholars and the industry experts' advices. The state characteristic of each level is shown in Table 2.

Table 2. Effectiveness levels' state characteristics of green mining ecological mine construction

Level	State	State characteristic
I	Very good	The effectiveness of green mining ecological mine construction is very good and consumes less resources. There is a higher utilization of resource, less emission and many advanced technologies. Ecological recovery is very fast and the low carbon management is very good.
II	Good	The effectiveness of green mining ecological mine construction is good and consumes a few resources. There is a high utilization of resource, less emission and some advanced technologies. Ecological recovery is fast and the low carbon management is good.
III	General	The effectiveness of green mining ecological mine construction is general and consumes a few resources. There is a general utilization of resource, general emission and some advanced technologies. Ecological recovery is not fast and the low carbon management is general.
IV	Poor	The effectiveness of green mining ecological mine construction is bad and consumes many resources. There is a low utilization of resource, much emission, and a few advanced technologies. Ecological recovery is slow and the low carbon management is poor.

Due to space limitations, the single index measure matrix of the TE is only taken as an example in this paper, and the other two matrixes can be got in the same way.

(1) Single index measure matrix u_{ijk}. Each single index measure matrix is given by the experts as the following (set the unevaluated mine as 1).

$$u_{1jk}^1 = \begin{bmatrix} 0.296 & 0.310 & 0.287 & 0.107 \\ 0.126 & 0.345 & 0.314 & 0.215 \\ 0.320 & 0.225 & 0.264 & 0.191 \\ 0.413 & 0.205 & 0.198 & 0.184 \\ 0.152 & 0.321 & 0.309 & 0.218 \\ 0.453 & 0.275 & 0.205 & 0.067 \\ 0.262 & 0.118 & 0.316 & 0.304 \\ 0.258 & 0.324 & 0.223 & 0.195 \\ 0.217 & 0.329 & 0.267 & 0.187 \\ 0.263 & 0.420 & 0.176 & 0.141 \\ 0.157 & 0.224 & 0.335 & 0.284 \\ 0.247 & 0.286 & 0.268 & 0.199 \end{bmatrix} \quad u_{1jk}^2 = \begin{bmatrix} 0.118 & 0.316 & 0.210 & 0.356 \\ 0.326 & 0.298 & 0.201 & 0.175 \\ 0.211 & 0.348 & 0.258 & 0.183 \\ 0.270 & 0.365 & 0.250 & 0.115 \\ 0.425 & 0.248 & 0.200 & 0.127 \\ 0.185 & 0.191 & 0.328 & 0.296 \\ 0.302 & 0.411 & 0.150 & 0.137 \\ 0.113 & 0.294 & 0.305 & 0.288 \\ 0.402 & 0.288 & 0.157 & 0.153 \\ 0.344 & 0.262 & 0.213 & 0.181 \\ 0.299 & 0.213 & 0.313 & 0.175 \\ 0.283 & 0.335 & 0.208 & 0.174 \end{bmatrix}$$

(2) According to the precedence chart and information entropy method, the index weight is obtained, and the weight preference coefficient μ is 0.5. The results are shown in Table 3.

(3) Comprehensive measure recognition matrix. After getting each index weight, the multi-index comprehensive measure recognition matrix can be calculated from the frontal

TABLE 3. Calculation results of index weight

Evaluation index (unit)	Precedence chart weight	Entropy weight	Comprehensive weight
The overall energy consumption of coal per ton (kgce/t)	0.0482	0.0497	0.04895
The overall power consumption of coal per ton (Kwh/t)	0.0468	0.0486	0.0477
Comprehensive energy consumption per unit of GDP	0.0211	0.0139	0.0175
Gangue utilization rate (%)	0.0478	0.0487	0.04825
Raw coal washing rate (%)	0.0317	0.0305	0.0311
Gas utilization rate (%)	0.1016	0.1265	0.11405
Mine water utilization rate (%)	0.0407	0.0434	0.04205
SO_2 emission (t)	0.0209	0.0138	0.01735
CO_2 emission (t)	0.0225	0.0174	0.01995
COD emission (t)	0.0657	0.0674	0.06655
Solid waste emission (t)	0.0299	0.0278	0.02885
"Three unders" mining rate (%)	0.0128	0.0066	0.0097
Air source heat pump and water source heat pump utilization rate (%)	0.0545	0.0567	0.0556
Water conservation mining rate (%)	0.0267	0.0248	0.02575
Gas extraction rate (%)	0.0218	0.0230	0.0224
Gob-side entry retaining rate and gob-side entry driving rate (%)	0.0501	0.0529	0.0515
Energy-saving equipment selection rate (%)	0.0713	0.0705	0.0709
Land reclamation rate (%)	0.0297	0.0243	0.027
Mining area greening rate (%)	0.0745	0.0777	0.0761
Waste dump governance rate (%)	0.0469	0.0450	0.04595
Corporate culture concept of low-carbon	0.0638	0.0634	0.0636
Low carbon management rules and regulations	0.0237	0.0224	0.02305
Employees low-carbon technologies training	0.0219	0.0208	0.02135
Community satisfaction	0.0254	0.0242	0.0248

single index measure matrixes. The multi-index comprehensive measure recognition matrix is as follows:

$$u_{10\times 5} = \begin{bmatrix} 0.2905 & 0.2977 & 0.2334 & 0.1785 \\ 0.2766 & 0.2988 & 0.2604 & 0.1642 \\ 0.3402 & 0.3722 & 0.1545 & 0.1331 \end{bmatrix}$$

(4) Level recognition and sorting. $u^1 = W^1 \cdot u_{1jk} = (0.2905, 0.2977, 0.2334, 0.1785)$ is the TE's evaluation vector which is calculated from Equation (7), and $\lambda = 0.7$. According to Equation (8), if $k_0 = 3$, then $0.2905 + 0.2977 + 0.2334 = 0.8216 > 0.7$. It means that the effectiveness of the TE's green mining ecological construction is in a good level. The effectiveness levels of the other two mines' construction can be got in the same way.

The effectiveness level rank of the three mines' construction can be obtained according to Equation (9), and it is shown in Table 4.

According to these results, we know that the effectiveness of the three mines' green mining ecological construction is in a good level.

5. **Conclusions.** This paper provides a feasible method for the evaluation of mine construction level. The positive evaluation result is really accurate, and it will provide a

Table 4. Effectiveness level rank of the three mines

Coal Mine	TY Coal Mine	TE Coal Mine	YJL Coal Mine
Grade	III	II	II
Score	2.4719	2.5236	2.6054

reference for the coal mining enterprises. Next, the coal mining enterprises will further use the green mining ecological construction model, reduce the generated waste from the source, build the industry ecosystem, realize the gangues do not liter of well, produce coal without burning coal, and protect groundwater. In order to ensure the evaluation result's accurateness and the study's persuasiveness, we will do a full comparison analysis for various evaluation methods further.

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REFERENCES

[1] J. G. Liu, Build low carbon ecological mining innovatively, strive to promote the science and technology development of enterprise, *Hebei Enterprise*, no.9, pp.65-67, 2011.
[2] J. G. Liu, Study and practice of low-carbon ecological mining construction of Jizhong Energy Group, *Journal of China Coal Society*, vol.3, no.2, pp.317-321, 2011.
[3] C. H. Xin, R. J. Ding and F. Liu, Multi-stage comprehensive evaluation model on low-carbon ecological mining construction in underground mine, *Journal of China Coal Society*, vol.37, no.6, pp.1061-1066, 2012.
[4] Q. K. Cao, X. Y. Ren, C. Liu et al., The analysis and study of the ability of technical innovation of enterprises based on rough set and unascertained measure appraisement model, *Systems Engineering-Theory & Practice*, no.4, pp.67-72, 2006.
[5] Q. K. Cao, Y. L. Yang and R. L. Yu, The coal mines safety appraisal based on unascertained set, *Journal of China Coal Society*, vol.32, no.2, pp.181-185, 2007.
[6] B. Jiang, J. J. Huang, W. W. Xie et al., Study on the construction planning of green Jintan salt mines, *China Mining Magazine*, vol.22, no.4, pp.42-45, 2013.
[7] M. X. Wang, M. G. Xu, P. Wang et al., Evaluation of green mine construction based on a new barrel theory, *China Mining Magazine*, vol.22, no.12, pp.68-72, 2013.
[8] J. M. Qin, Z. G. Kang, Y. P. Cao et al., Discovery and practices on construction of ecological mine with low carbon operation, *Coal Economic Research*, vol.33, no.12, pp.45-49, 2013.
[9] F. S. Qiao, The ecological civilization throughout the green mine construction process, *China Mining Magazine*, vol.22, no.1, pp.53-56, 2013.
[10] X. C. Liu, Exploration and practice of Zhaojin mining Co., *China Mining Magazine*, vol.20, no.5, pp.45-48, 2011.