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Abstract. Based on AHP method, this paper built the evaluation model of coal mine sustainable development and calculated weight of each indicator, the essay aims at providing an effective method for the scientific development of coal mine. In addition, on the basis of the evaluation index system of sustainable development, the fuzzy comprehensive evaluation method was used to comprehensively evaluate four major coal mines of Shen Yang Coal Industry Group.

Key words: AHP method; Fuzzy comprehensive evaluation; Index system; Sustainable development.

1. Foreword

Coal resource is a kind of non-renewable and one-off resource, the sustainable development of the coal enterprises is not only a positive response to the national policy, but also an inevitable requirement of the development of coal enterprises. Ananth P. Chikkatur, Ambuj D. Sagar, T.L. Sankar introduced the importance of coal mine sustainable development on economic development[1];Gao Zhenguo put forward the importance of improving the coal industry technical level and the transformation of economic development mode, he did research on coal mine sustainable development mechanism from the aspects of labor, development method and development goal[2];Adisa Azapagic (2004)established the mining industry sustainable development index system according to the mining industry sustainable development project implemented by the British Department of Mining and Minerals[3];Kemal Baris [4] and Lu Yinming[5] et al also successively put forward some improvement measures for coal mine sustainable development. This paper evaluated the main coal mines of Shen Yang Coal Industry Group based on the index system of coal mine sustainable development.

2. The approach of AHP method

2.1. Hierarchical structure

Based on the analysis of the problem, the complicated problem is decomposed into several components, these components are subdivided into several groups according to the attribute, which forms the hierarchical structure.

2.2. Generation of the judgment matrix

Two factors are selected each time, a_{ij} represents the relative importance of each factor. All the results of the comparison are listed in matrix A, witch forms the judgment matrix, matrix values are given by experts in the field, as shown in equation(1).

$$A=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & & a_{2n} \\ \vdots & & & \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{1}$$

2.3. Evaluation of the judgment matrix

2.3.1. Quantification of the elements. in order to quantify each element of the judgment matrix, this paper adopt Satty 1-9 graphic evaluation method.

2.3.2. Consistency check .in the model of Satty's method, the importance degree of each two elements are evaluated by numbers 1-9. However, some decimal circular and round could undermine the consistency of the matrix, for example, Nonzero eigenvalue λ_{max}=m, in addition, when the importance of elements i, j, k are close to each other, common problems may occur in the comparison work of the experts, namely element j is more important than i, while element i is mare important than k and element k is more important than j. Therefore, there may be inconsistency in the matrix formed by comparing each two elements. In AHP method, consistent rate CR is generally used to to check the consistency of the matrix, as shown in equation (2).

$$C_{ij}=1/C_{ji} \qquad \lambda_{\max}=\frac{1}{m}\sum_{i=1}^{m}\frac{(\mathrm{A}\,\delta)_i}{\delta_i} \tag{2}$$

$$CR=CI/RI \qquad CI=\frac{\lambda_{\max}-m}{m-1} \tag{3}$$

Among witch CI is the consistency of each element, m represents the order of the judgment matrix, λ_{max} represents the maximum eigenvalue of the judgment matrix, RI represents the random consistency index, as shown in table 1.

Table 1. Random consistency index corresponding table

n	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

When CR increases, the consistency of the matrix decreases and vice versa. The matrix is completely consistent when λ_{max}=n, CR=0. Generally when CR is less than 0.1, the matrix passes the consistency check. Otherwise, the comparison of the elements should be done again, until the matrix satisfies the consistency check.

2.3.3. Determination of the relative weight of each element. After the judgment matrix passes the consistency check, to calculate eigenvalue $A\lambda=n\lambda$ leads to the result that $\lambda=\left(\lambda_1,\lambda_2,\cdots\lambda_n\right)^T$, its

normalized result is the weight of the elements. Many scholars proposed other weight calculation methods, such as the upper triangular element method and the ordinary least squares (OLS), these methods have their own advantages under different conditions.

3. Construct the evaluation index system of coal mine sustainable development

3.1. Framework of the index system

The index system is based on AHP method. Firstly, the main factors influencing coal mine sustainable development are defined, then the weight of main factors are calculated. The weight of the underlying index could be calculated by analogy. The sustainable development system of coal mine is a gradual coupling operating system, it includes three levels of structure.

(1) Strategy level A, this level fully reflects the trend of coal mine sustainable development, and it is the overall goal of the development of coal enterprise.

(2) System level B, the overall development goal of coal enterprise is decomposed into mine resources and energy consumption indicator, mine pollution control indicator, mine comprehensive utilization of resource indicator, mine ecological protection indicator and mine ecological management indicator.

(3) Index level C, this level are specific elements that influence the sustainable development of coal mine, which includes 18 indicators.

3.2. Build the hierarchical structure model

In the AHP method, the five kinds of elements and 18 indicators are shown in table 2[6].

Table 2. AHP hierarchical structure model

Strategy level	System level	Index level
The evaluation index system of coal mine sustainable development, A	Mine resources and energy consumption indicator, B1	The extraction rate
		Energy consumption per unit of product
	Mine pollution control indicator, B2	The concentration of nitrogen oxide emissions
		SO^2 emission concentration
		The emission concentration of ammonia nitrogen
		Chemical oxygen demand
		Solid waste emissions per unit of product
	Mine comprehensive utilization of resource indicator, B3	Associated mineral mining rate
		Mine water utilization rate
		Industrial water recycling rate
		Coal bed gas utilization rate
		Solid waste utilization
	Mine ecological protection indicator, B4	Subsidence land reclamation rate
		The gangue (soil) plant afforest rate
		Mine industry square greening rate
		The protection level of mine water
	Mine ecological management indicator, B5	Consummate level of management system
		The level of mine construction sustainable development

4. Empirical study on the sustainable development of coal mine

AHP method is adopted in this paper, the weight of system level is calculated, and the weight of index level is calculated, the weights of all the indicators are shown in table 3.

Table 3. Evaluation index of coal mine sustainable development

Strategy level	System level	Index level	Weights
The evaluation index system of coal mine sustainable development, A	Mine resources and energy consumption indicator, B1 0.1528	The extraction rate C_{11}	0.0501
		Energy consumption per unit of product C_{12}	0.1027
	Mine pollution control indicator, B2 0.2318	The concentration of nitrogen oxide emissions C_{21}	0.0254
		SO^2 emission concentration C_{22}	0.0746
		The emission concentration of ammonia nitrogen C_{23}	0.0982
		Chemical oxygen demand C_{24}	0.0235
		Solid waste emission per unit of product C_{25}	0.0101
	Mine comprehensive utilization of resource indicator, B3 0.3752	Associated mineral mining rate C_{31}	0.0392
		Mine water utilization rate C_{32}	0.0582
		Industrial water recycling rate C_{33}	0.0664
		Coal bed gas utilization rate C_{34}	0.0827
		Solid waste utilization C_{35}	0.1287
	Mine ecological protection indicator, B4 0.1721	Subsidence land reclamation rate C_{41}	0.0331
		The gangue (soil) plant afforest rate C_{42}	0.0839
		Mine industry square greening rate C_{43}	0.0106
		The protection level of mine water C_{44}	0.0445
	Mine ecological management indicator, B5 0.0681	Consummate level of management system C_{51}	0.0565
		The level of mine construction sustainable development C_{52}	0.0116

Based on the fuzzy comprehensive evaluation method, scores are divided into four phases, as shown in table 4, by expert interviews, the scores of Lin Sheng coal mine, Hong Yangsan coal mine, Hong Ling coal mine and Xi Ma coal mine of Shen Yang Coal Energy Group are obtained, this paper took Lin Sheng coal mine as an example, as shown in table 5.

Table 4. Coal mine sustainable development evaluation hierarchy criteria

Evaluation level	Excellent	Good	Average	Poor
Quantitative numerical	80~100	60~80	40~60	0~40

Table 5. Lin Sheng coal mine of Shen Yang Coal Energy Group sustainable development index membership degree

Strategy level	System level	Index level
The evaluation index system of coal mine sustainable development, A (0.282,0.392,0.265,0.061)	Mine resources and energy consumption indicator, B1 (0.4,0.4,0.1,0.1)	The extraction rate(0.5,0.3,0,0.2)
		Energy consumption per unit of product(0.3,0.5,0.2,0)
	Mine pollution control indicator, B2 (0.14,0.46,0.34,0.06)	The concentration of nitrogen oxide emissions(0.1,0.4,0.5,0)
		SO^2 emission concentration (0.1,0.4,0.4,0.1)
		The emission concentration of ammonia nitrogen(0.1,0.5,0.3,0.1)
		Chemical oxygen demand (0.3,0.5,0.2,0)
		Solid waste emission per unit of product (0.1,0.5,0.3,0.1)
	Mine comprehensive utilization of resource indicator, B3 (0.32,0.4,0.26,0.02)	Associated mineral mining rate (0.2,0,3,0.5,0)
		Mine water utilization rate (0.5,0.3,0.2,0)
		Industrial water recycling rate (0.2,0.5,0.2,0.1)
		Coal bed gas utilization rate (0.4,0.4,0.2,0)
		Solid waste utilization (0.3,0.5,0.2,0)
	Mine ecological protection indicator,B4 (0.25,0.35,0.275,0.125)	Subsidence land reclamation rate (0,0.2,0.5,0.3)
		The gangue (soil) plant afforest rate (0.2,0.3,0.4,0.1)
		Mine industry square greening rate (0.6,0.4,0,0)
		The protection level of mine water (0.2,0.5,0.2,0.1)
	Mine ecological management indicator, B5 (0.3,0.35,0.35,0)	Consummate level of management system (0.1,0.4,0.5,0)
		The level of mine construction sustainable development (0.5,0.3,0.2,0)

Basing on the coal mine sustainable development index system, developed the Lin Shen coal mine first level sustainable development index evaluation value as follows.

The overall sustainable development evaluation value of Lin Shen coal mine is:

$$U = (0.282, 0.392, 0.265, 0.061) \bullet \begin{bmatrix} 100 \\ 80 \\ 60 \\ 40 \end{bmatrix} = 54.90$$

Basing on the same method, the first level index of sustainable development evaluation value for the other three coal mines are calculated as shown in table 6.

Table 6. Comprehensive sustainable development evaluation value of 4 coal mines

Coal Mine	Comprehensive sustainable development evaluation value
Lin Shen Coal Mine	54.90
Hong Yang Coal Mine	84.65
Hong Ling Coal Mine	68.34
Xi Ma Coal Mine	70.22

5. Calculation result and analysis

In the evaluation index method basing on AHP method, the factor of coal mine pollution control and coal mine resource comprehensive utilization are two of the most important factors, their index weight are respectively 0.2318 and 0.3752, the weight of these two factors are obviously higher than the other three factors, namely consumption of coal mine resource and energy factor, coal mine ecological protection factor and coal mine ecological management factor.

Based on fuzzy comprehensive evaluation method, it is found that the sustainable development ability of Hong Yang coal mine is the best, the sustainable development ability of Lin Shen coal mine is the worst, their evaluation valve are respectively 84.65 and 54.90. Therefore the Lin Shen coal mine should improvement their comprehensive performance through coal mine pollution control and coal mine resource comprehensive utilization. The sustainable development ability of Hong Ling coal mine and Xi Ma coal mine are in the middle of the four coal mines, their evaluation result are respectively 68.34 and 70.22, by improving the 5 index factors in the evaluation system, the sustainable development ability of these two coal mines can be elevated from favorable to excellent.

6. Conclusion

(1) The sustainable development of coal mine has close relationship with the five factors, including the consumption of coal mine resource and energy factor, coal mine ecological protection factor, coal mine ecological management factor, coal mine pollution control and coal mine resource comprehensive utilization factor.

(2) Coal mine should pay more attention to these five factors, especially the factor of coal mine pollution control and coal mine resource comprehensive utilization factor. Basing on this conclusion, coal mine should enhance the coal mine environment pollution control and investigate more founds into the comprehensive utilization of resource to achieve sustainable development.

(3) The sustainable development ability of Hong Yang coal mine is the best among the four coal mines. The sequence of sustainable development ability of the four coal mines are as follows.

Lin Shen coal mine<Hong Ling coal mine<Xi Ma coal mine<Hong Yang coal mine

(4) It is necessary for each coal mine to recognize the gap between themselves and other coal mines, they should be aware of the reason why their sustainable development ability is behind others, make the improvement strategy and take actions, improve the comprehensive resource utilization of the coal mine, promote the sustainable development of the enterprise.

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