Research on Comprehensive Efficiency Evaluation of Mineral Resources Development

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Abstract. Based on the analysis of ecological economy and circular economy of mineral resources development, this study establishes a comprehensive efficiency evaluation index system from three aspects: resource utilization efficiency, ecological compensation efficiency and development benefit efficiency, and uses the entropy method to determine the index weight. The comprehensive efficiency levels are evaluated by the TOPSIS analysis method. Through the empirical research, the sample enterprises have been comprehensively evaluated. The evaluation results show the reliability and practicability of the evaluation indicators and evaluation methods, and provide reference for the future high-quality development of the enterprise.

1. Introduction

Mineral resources are non-renewable resources, and comprehensively improving the high-efficiency development of mineral resources is of great significance to the sustainable development of the national economy, the maximum resource efficiency of enterprises, and the optimal allocation of mineral resources. As the main body of resource development, mining enterprises need to pay more attention to the quality of mineral resources development and utilization, while expanding production capacity and improving quality under the conditions of limited resources. The comprehensive efficiency of mineral resources development not only covers the utilization rate of mineral resources development, but also includes the economic, environmental and social benefits generated by the development of mineral resources. Scientifically and objectively evaluate the level of development and utilization of mineral resources in mines or a certain area, which are in order to understand and analyze the problems existing in the development of mineral resources. This evaluation method can provide technical support for rational development and utilization of resources in mine production, and provide countermeasures for government supervision [1]. The comprehensive efficiency evaluation of mineral resources development is a complex system. This paper has only made a shallow discussion on the establishment of a scientific evaluation index system and the construction of a reasonable evaluation model.

2. Comprehensive efficiency evaluation index system for mineral resources development

2.1. Indicator meaning

Based on the concept of green development and utilization, this paper constructs an evaluation index system from three aspects: resource utilization efficiency subsystem, ecological compensation efficiency subsystem and development benefit efficiency subsystem, as a method to measure the
comprehensive efficiency evaluation of mineral resources development projects. Resource utilization efficiency refers to the extent to which the useful ingredients and waste are fully utilized. The company adopts advanced technology and scientific management to produce the mineral products that can best use its purpose with the lowest resource consumption, minimum environmental impact and safety cost [2]. The ecological compensation efficiency subsystem means the extent to which the negative externalities affect the governance effect in the mining area such as ecology is restored. The development benefit efficiency subsystem measures the degree of resource development from the economic factors such as product processing value and investment income level [3].

2.2. Selection principle
The principles are followed when selecting secondary evaluation indicators. First, the selected indicators should be actually, and will not change due to the subjective consciousness of the evaluator in the evaluation process. Second, the representative principle is selected. The evaluation index should be a representative indicator, which can clearly reflect the characteristics of a certain aspect, and should not be selected for indicators with little relevance. Third, a series of aspects should be made as much as possible. The evaluation indicators can cover this aspect, and should not be missed or duplicated as much as possible. Finally, the selected evaluation indicators should be able to obtain results and energy through calculation, data review, social research or other methods. It is convenient to calculate comprehensive indicators and evaluate them.

2.3. Indicator system
From the micro level, the comprehensive efficiency evaluation index system is as shown in Table 1. The author believes that the comprehensive efficiency evaluation of mineral resources development is essentially a quantitative measurement of the indicators, and then measure the coordination of the resource utilization of the development project - ecological compensation - the economic income system. The higher the degree of coordination indicates the higher efficiency. On the contrary, the lower degree of coordination is the worse.

3. Constructing a comprehensive efficiency evaluation model for the development of mineral resources
The measurement model used in this paper is mainly divided into two parts. First part is to calculate the three subsystem evaluation values based on TOPSIS method, and use the evaluation value to characterize the advantages and disadvantages of the three subsystems. Second part is to measure the coordination status of the whole system by introducing coordination degree function. Then the comprehensive efficiency is evaluated.

| Table 1. Comprehensive efficiency evaluation index system for mineral resources development |
|-----------------------------------------------|
| **Target layer**                               | **Primary indicator** | **Secondary indicators** |
| Comprehensive efficiency evaluation           | X₁ Resource utilization efficiency | X₁₁ Mining recovery rate |
|                                              |                         | X₁₂ mineral separation recovery rate |
|                                              |                         | X₁₃ Comprehensive utilization |
|                                              |                         | X₁₄ Waste utilization |
|                                              |                         | X₁₅ Selected grade rate |
|                                              | X₂ Ecological compensation efficiency | X₂₁ Geological environment restoration rate |
|                                              |                         | X₂₂ Air pollution control rate |
|                                              |                         | X₂₃ Water pollution control rate |
|                                              |                         | X₂₄ Vegetation restoration rate |
|                                              |                         | X₁₅ Unit mine profit margin |
### 3.1. Data processing

Firstly, data of the evaluation indexes are selected and performed the forward processing on the obtained data to construct the original matrix.

\[
Y = \begin{bmatrix}
    a_{11} & a_{12} & \cdots & a_{1n} \\
    a_{21} & a_{22} & \cdots & a_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    a_{m1} & a_{m2} & \cdots & a_{mn}
\end{bmatrix}_{m \times n}
\]

Secondly, data in the original matrix should be normalized to obtain a normalized matrix.

\[
G = \begin{bmatrix}
    g_{11} & g_{12} & \cdots & g_{1n} \\
    g_{21} & g_{22} & \cdots & g_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    g_{n1} & g_{n2} & \cdots & g_{nn}
\end{bmatrix}_{n \times n}
\]

At last, we can use entropy method to determine the weight of m evaluation indicators in the subsystem, and obtain the weight matrix. \( \omega \) indicates the weight of the indicator in the subsystem.

\[
Z = \begin{bmatrix}
    z_{i1} & z_{i2} & \cdots & z_{im} \\
    z_{i21} & z_{i22} & \cdots & z_{i2m} \\
    \vdots & \vdots & \ddots & \vdots \\
    z_{in1} & z_{in2} & \cdots & z_{inn}
\end{bmatrix}_{m \times m}
\]

\[
Z_{ij} = \omega_j \times g_{ij} \quad i = 1,2,3,\ldots,n, j = 1,2,3,\ldots,m
\] (1)

### 3.2. Calculated evaluation value

The maximum and minimum values of each index are respectively selected. The optimal weight vector and the worst weight vector are respectively \( Z_j^+ \) and \( Z_j^- \). Calculate the distance between each evaluation index and the optimal vector, simultaneously calculate the worst vector.

\[
D_j^+ = \sqrt{\sum_{i=1}^{n} (z_{ij} - z_{ij}^+)^2} \quad (2)
\]

\[
D_j^- = \sqrt{\sum_{i=1}^{n} (z_{ij} - z_{ij}^-)^2} \quad (3)
\]

Calculate the extent to which the subsystem approaches the optimal value. That is the overall evaluation value of the subsystem.

\[
S = \frac{D_j^-}{D_j^+ + D_j^-},
\]

According to the processes of (1) to (4) above, the evaluation values of other subsystems can be obtained. Regardless of the impact of indicator weights on coordination, the coordination of the three subsystems is calculated using the formula below.
\[ C = \frac{S_1 + S_2 + S_3}{\sqrt{S_1^2 + S_2^2 + S_3^2}} \]  

(5)

4. Empirical Research

For specific mining enterprises, many factors will affect the comprehensive evaluation, such as the development scale of the mine, its own resource conditions, the production technology of the enterprise and the management performance. In order to make the data comparable and the results more reliable, five mining enterprises of similar production scale in the same region were selected as research objects (which are marked as Q1, Q2, Q3, Q4, Q5). In this evaluation, indicator data of the same year were collected for analysis. Firstly, the evaluation value of the resource utilization efficiency subsystem is calculated. According to the above comprehensive efficiency evaluation model, the calculation process is as follows:

4.1. The raw data are normalized to obtain a normalized matrix:

\[
G = \begin{bmatrix}
0.4463 & 0.4028 & 0.484 & 0.4281 & 0.4466 \\
0.4609 & 0.4799 & 0.4792 & 0.4795 & 0.4895 \\
0.4470 & 0.4628 & 0.4105 & 0.4418 & 0.4422 \\
0.4413 & 0.4291 & 0.4416 & 0.4692 & 0.4244 \\
0.4403 & 0.4571 & 0.4155 & 0.4144 & 0.4303 \\
\end{bmatrix}
\]

4.2. The weight of the five evaluation indicators are using to obtain the weight matrix:

\[
\omega = (0.154, 0.167, 0.32, 0.192, 0.167),
\]

\[
Z = \begin{bmatrix}
0.0687 & 0.0672 & 0.1548 & 0.0821 & 0.0745 \\
0.0709 & 0.0801 & 0.1533 & 0.0920 & 0.0817 \\
0.0688 & 0.0772 & 0.1313 & 0.0848 & 0.0738 \\
0.0679 & 0.0716 & 0.1413 & 0.0900 & 0.0708 \\
0.0678 & 0.0763 & 0.1329 & 0.0795 & 0.0718 \\
\end{bmatrix}
\]

4.3. Evaluation results and analysis

| Serial number | D* | D- | S | Ranking |
|---------------|-----|----|---|---------|
| Q1            | 0.0178 | 0.024 | 0.5741 | 2 |
| Q2            | 0.0015 | 0.0305 | 0.9531 | 1 |
| Q3            | 0.0261 | 0.0117 | 0.3095 | 4 |
| Q4            | 0.0196 | 0.0151 | 0.4351 | 3 |
| Q5            | 0.0275 | 0.0059 | 0.1766 | 5 |

As can be seen from Table 2 that Q2 has the highest evaluation value, which is close to the optimal. It can be preliminarily judged that the mine enterprise has the highest resource utilization efficiency in all the evaluation mines. Q5 is farthest from the optimal value and the evaluation value is also the lowest. It can be found that the mining enterprise has the lowest resource utilization efficiency in all the evaluated mines. The main reason is that the comprehensive utilization rate and the selected grade rate account for a relatively large index value. It makes the comprehensive evaluation value of Q5 low. However Q2 has more advantages in these aspects. Therefore, the comprehensive efficiency
evaluation results objectively reflect the level of resource utilization of participating mining enterprises.

4.4. Coordination degree and analysis

Using the same method, the evaluation values of the ecological compensation efficiency and development benefit efficiency can be obtained. Next the coordination degree of the three subsystems needs to be calculated.

| Serial number | S1     | S2     | S3     | C        |
|---------------|--------|--------|--------|----------|
| Q1            | 0.5741 | 0.8195 | 0.3937 | 1.6623   |
| Q2            | 0.9531 | 0.2753 | 0.2677 | 1.4561   |
| Q3            | 0.3095 | 0.1093 | 0.0182 | 1.3295   |
| Q4            | 0.4351 | 0.4077 | 0.2858 | 1.7069   |
| Q5            | 0.1766 | 0.5942 | 0.9426 | 1.5187   |

From Table 3, it can be found that in the evaluation of three subsystems, the resource utilization efficiency level of Q2 is the highest and the ecological compensation efficiency level of Q1 is the highest. At the same time, the development benefit efficiency level of Q5 is the highest. Each enterprise has its own advantages and disadvantages in different subsystems. For example, Q5 has certain efficient development benefits, but needs to improve resource utilization efficiency. In order to comprehensively evaluate the development efficiency of mineral resources, we combined with the coordination degree of the three subsystems for evaluation. The results show the highest coordination degree is Q4 and the lowest coordination degree is Q3. It can be judged that the best overall efficiency evaluation is Q4 and the worst is Q3. Therefore, the recommendations for the high-quality development of enterprises in the future are three points: (1) Strengthening the conservation and intensive use of mineral resources. Enterprises need to continuously improve their technology and improve their management level. They can measure the level of resource utilization of mining enterprises by the degree of compliance of the actual resource utilization efficiency indicators of enterprises with the advanced standards of the industry [4]. (2) Promoting the green development of mining enterprises. Mining enterprises should reduce pollution and environmental costs for achieving the harmonious coexistence of mineral resources utilization and ecosystem [5]. (3) Improving the development effect of mineral resources and broadening the value-added space of products. We should consider the advantages of superior minerals and the effect of the efficient use of mineral products on the economic benefits of enterprises.

5. Conclusion

Accurately evaluating the comprehensive efficiency level of mineral resources development will help enterprises to identify problems and provide direction for enterprises to maximize resource efficiency. This paper provides a preliminary analysis platform for the evaluation of the economic efficiency of mineral resources. The evaluation index of comprehensive efficiency and the establishment of evaluation model can provide direction for the decision-making of mining enterprises. At present, the research on the comprehensive efficiency of mineral resources development is still relatively shallow. Further research is needed for the selection and quantitative evaluation.

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