International Journal of Energy
ISSN: 2957-9473 | Vol. 3, No. 1, 2023

Online Evaluation Method for Carbon Performance of Coal Mines Owned by the Coal Industry Group based on Combination of Subjective and Objective Weights

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Abstract: An online evaluation method for carbon performance of coal mines owned by the coal industry group based on combination of subjective and objective weights is proposed. Firstly, the evaluation method for carbon performance of coal mines owned by the coal industry group based on combination of subjective and objective weights is proposed: (1) The index system of carbon performance evaluation of coal mines owned by the coal industry group is constructed. (2) The objective weight of each index is obtained by entropy weight method. (3) The subjective weight of each index is obtained by Delphi method. (4) The comprehensive weight of each index is obtained by weighted average method. (5) The score of each index of each coal mine is obtained by linear interpolation method. (6) The comprehensive evaluation score of each coal mine is obtained by weighted average method. Secondly, taking Sql server as the database management system, ASP and C# as the development language, Dreamweaver and Visual Studio as the development platform, the system of carbon performance evaluation of coal mines owned by the coal industry group based on B/S structure is designed, and the system can realize online evaluation for carbon performance of coal mines. Finally, the application analysis results show that the method can ensure the objectivity of carbon performance evaluation of coal mines, greatly improve the efficiency of evaluation, and realize sharing and comparison of the evaluation results.

Keywords: Combination of Subjective and Objective Weights; Carbon Performance Evaluation; Online Evaluation; Entropy Weight Method.

1. Introduction

China is currently the world's largest emitter of CO_2, and therefore China plays an important role in mitigating global climate change[1-2]. In 2020, General Secretary Xi announced at the 75th session of the United Nations General Assembly that China would achieve "carbon peak" before 2030 and "carbon neutrality" before 2060, referred to as the "double carbon" goal[3-4]. In order to achieve the "double carbon" goal, the energy and chemical industries will take the lead, and other industries will also participate in the process one after another[5-8]. In this context, as a coal industry group, it is necessary to evaluate the carbon performance of its coal mines in order to identify the focus of improvement, so as to contribute to the improvement of the group's overall carbon performance and the achievement of the " double carbon " goal.

Commonly used methods for carbon performance evaluation include life cycle evaluation method, balanced scorecard evaluation method, analytic hierarchy process evaluation method, fuzzy comprehensive evaluation method, input-output model[9-14]. Since the weighted average method is simple and practical, it is widely used in practice. So the weighted average method is used for carbon performance evaluation of coal mines in this paper. The determination of index weights is an important step in the carbon performance evaluation of weighted average. Commonly used methods for determining weights include AHP method, Delphi method, entropy weight method[15-18]. If we adopt AHP method and Delphi method to determine subjective weights, the advantage is that the weights can better reflect the importance of indexes, and the disadvantage is that the weights are influenced by subjective will. If we adopt entropy weight method to determine objective weights, the advantage is that the weights only depend on the quantitative value of each index and are not affected by subjective will, and the disadvantage is that the weights only reflect the amount of difference between the quantitative values of the indexes, but not the importance of the indexes.Therefore, a more reasonable method for determining weights is to combine the two methods, i.e., to combine subjective weights with objective weights to determine the comprehensive weights [19]. However, this evaluation method of combining subjective and objective weights has three main drawbacks if it is carried out in an offline manner. First, the evaluator's workload of collecting data is large, data are difficult to collect completely, and accuracy of the data is difficult to be guaranteed. Second, the process of calculation is more cumbersome and error-prone. Third, it is difficult to share the evaluation results, which is not conducive to being inquired and compared among the evaluated coal mines.

Based on this, an online evaluation method for carbon performance of coal mines owned by the coal industry group based on combination of subjective and objective weights is proposed in this paper.

2. The Method for Carbon Performance Evaluation of Coal Mines Owned by the Coal Industry Group based on Combination of Subjective and Objective Weights

The evaluation process of the method for carbon performance evaluation of coal mines owned by the coal

industry group, which combines subjective and objective weights, is shown in Figure 1.

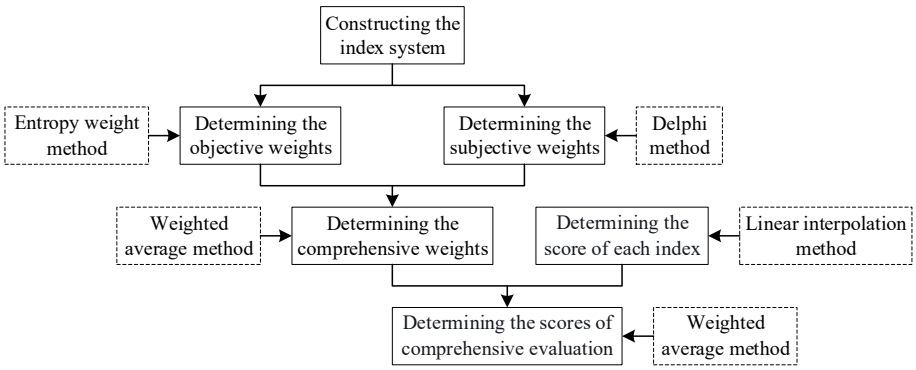


Figure 1. The flow chart of carbon performance evaluation of coal mines owned by the coal industry group based on combination of subjective and objective weights

(1) Construct the evaluation index system of carbon performance for coal mines owned by the coal industry group.

(2) Determine the objective weight of each index by entropy weight method according to the following steps [20-22]:

1) Construct the evaluation matrix *X*.

$$X = (x_{ij})_{m\times n} \tag{1}$$

In matrix X, the element x_{ij} is the value of index *i* of the *j*th coal mine, *i*=1, 2, 3……*m*; *j*=1, 2, 3……*n*. *m* is the quantity of the indexes. *n* is the quantity of the evaluated coal mines.

2) Standardize x_{ij} by formula (2) or (3).

If $x_{imax} \neq x_{imin}$, transform x_{ij} to r_{ij} for positive indexes by formula (2), otherwise let r_{ij} =1.

$$r_{ij} = \frac{x_{ij}-x_{imin}}{x_{imax}-x_{imin}} \tag{2}$$

If $x_{imax} \neq x_{imin}$, transform x_{ij} to r_{ij} for negative indexes by formula (3), otherwise let r_{ij} =1.

$$r_{ij} = \frac{x_{imax}-x_{ij}}{x_{imax}-x_{imin}} \tag{3}$$

In formula(2) and (3), the elements x_{imax}、x_{imin} are the maximum value and minimum value of index *i* of the evaluated coal mines, and r_{ij} is the value after standardizing x_{ij}.

3) Obtain the objective weights by formula (4)~(6).

$$f_{ij} = \frac{r_{ij}}{\sum_{j=1}^{n} r_{ij}} \tag{4}$$

In formula (4), the element f_{ij} is the weight of index *i* of the *j*th coal mine.

$$h_i = -\frac{1}{\ln n}\sum_{j=1}^{n} f_{ij}\ln f_{ij} \tag{5}$$

In formula (5), the element h_i is the information entropy of index *i*, and $f_{ij}\ln f_{ij}$ can be transformed to $\frac{\ln f_{ij}}{\frac{1}{f_{ij}}}$. According to Lopita rule, when $f_{ij}\to 0$, $\frac{\ln f_{ij}}{\frac{1}{f_{ij}}}\to 0$. Therefore, when $f_{ij}=0$, let $f_{ij}\times\ln f_{ij}=0$.

$$w_{oi} = \frac{1-h_i}{m-\sum_{i=1}^{m} h_i} \tag{6}$$

In formula (6), the element w_{oi} is the objective weight of index *i*.

(3) Determine the subjective weight of each index by Delphi method.

(4) Determine the comprehensive weight of each index by weighted average of its subjective weight and objective weight by formula (7).

$$w_{ci} = w_{Oi}\times\alpha + w_{si}\times(1-\alpha) \tag{7}$$

In formula (7), the element w_{ci} is the comprehensive weight of index *i*, α is the objective weight coefficient of index *i*, and w_{si} is the subjective weight of index *i*.

(5) Determine the score of each index of each coal mine by linear interpolation according to the value of each index of each coal mine and the corresponding lower limit *a* and upper limit *b* [23-24].

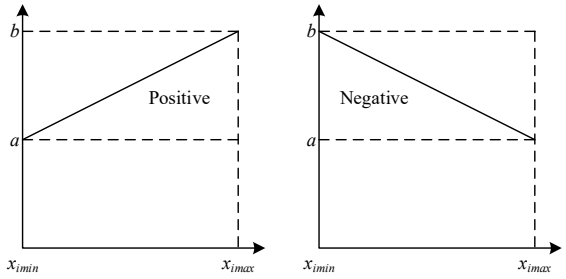


Figure 2. The linear interpolation method to obtain the score of each index of each coal mine

If $x_{imax} \neq x_{imin}$, transform x_{ij} to y_{ij} for positive indexes by formula (8), otherwise let $y_{ij} = b$.

$$y_{ij} = a + \frac{b-a}{x_{imax}-x_{imin}}(x_{ij}-x_{imin}) \tag{8}$$

If $x_{imax} \neq x_{imin}$, transform x_{ij} to y_{ij} for negative indexes by formula (9), otherwise let $y_{ij} = b$.

$$y_{ij} = b + \frac{a-b}{x_{imax}-x_{imin}}(x_{ij}-x_{imin}) \tag{9}$$

In formula (8) and (9), the element y_{ij} is the score of index *i* of the *j*th coal mine.

(6) Determine the comprehensive evaluation score of each coal mine by formula (10).

$$s_j = \sum_{i=1}^{m} y_{ij}\times w_{ci} \tag{10}$$

In formula (10), the element s_j is the comprehensive evaluation score of the *j*th coal mine.

3. Design of Online Evaluation System for Carbon Performance Evaluation of Coal Mines Owned by the Coal Industry Group based on the Combination of Subjective and Objective Weights

3.1. Business Process Design

The business process of online evaluation for carbon performance of coal mines owned by the coal industry group are as follows:

(1) Construct the index system of carbon performance

evaluation of the coal mines by the group administrator.

(2) Assign the tasks of carbon performance evaluation before the annual carbon performance evaluation by the group administrator.

(3) Submit the data of carbon performance evaluation within the specified time by the coal mine evaluators.

(4) Audit the data of carbon performance evaluation of the coal mines by the group administrator.

(5) Reject the data and fill in the reasons for rejection by the group administrator if the data of carbon performance evaluation are found to be faulty or doubtful during the audit.

(6) Correct the rejected data and fill in the revision instructions in the submission instructions by the coal mine evaluators.

(7) Calculate the carbon performance based on the data of carbon performance evaluation of the coal mines by the group administrator when all data of carbon performance evaluation have passed the audit.

(8) View the carbon performance of each coal mine and make a horizontal comparison of carbon performance of different coal mines in the same year or a vertical comparison of carbon performance of the same coal mine in different years by the group administrator after the completion of calculation.

(9) View the carbon performance of this coal mine and make a vertical comparison of carbon performance of this coal mine in different years by the coal mine evaluators after the completion of calculation.

3.2. Function Planning

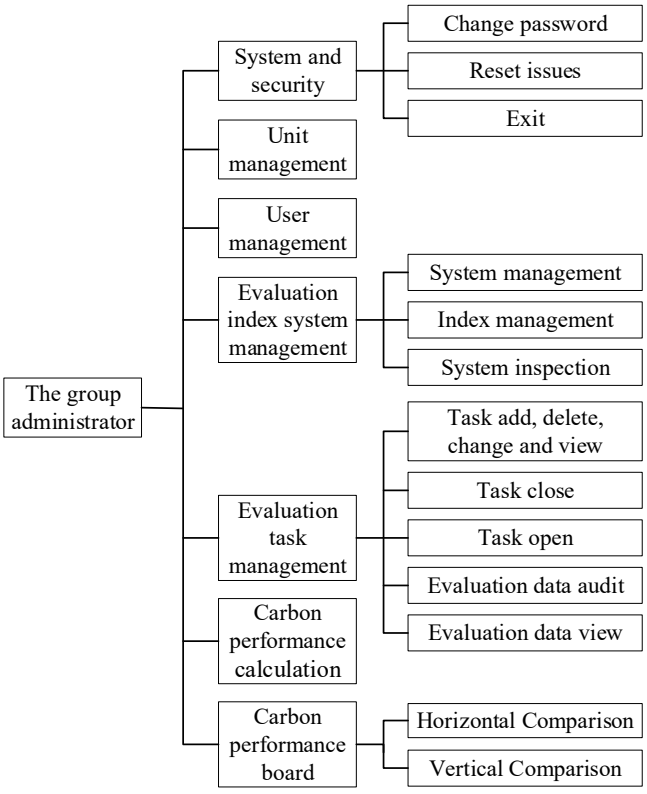


Figure 3. The functional modules of group administrator

There are two types of roles in the system: the group administrator and the coal mine evaluators. The group administrator is mainly responsible for constructing the index system of carbon performance evaluation of coal mines, assigning the tasks of carbon performance evaluation, auditing the data of carbon performance evaluation, calculating carbon performance, and viewing the carbon performance of each mine, whose functional modules are shown in Figure 3. Coal mine evaluators are mainly responsible for submitting the data of carbon performance evaluation and viewing the carbon performance of this mine, whose functional modules are shown in Figure 4.

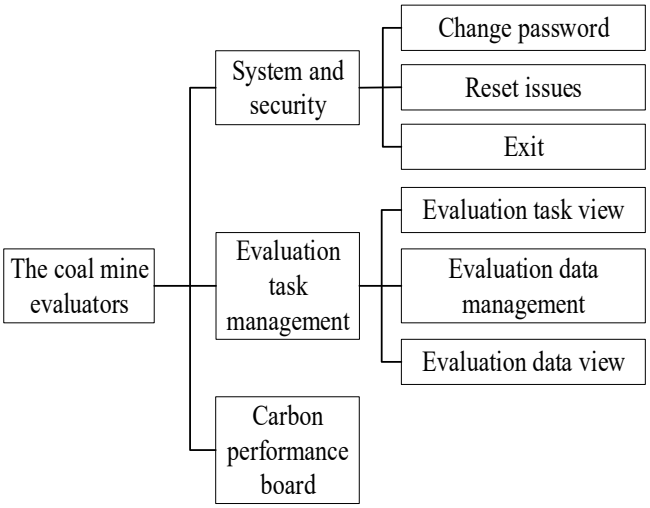


Figure 4. The functional modules of coal mine evaluators

3.3. Database Design

Taking Sql server as the database management system, the database required for the system is designed according to the principle of normative design. The database mainly includes 7 data tables, including Unit, User, Index system, Index, Task of carbon performance evaluation, Detail of carbon performance evaluation, and Value of carbon performance evaluation, and the relationship between the tables is shown in Figure 5.

The data table "Unit" is used to store information about the coal mines owned by the coal industry group. The field "Display order" is used to control the order which the horizontal units appear in the board of carbon performance. The data table "User" is used to store the information of the legal users of the system. The data table "Index system" is used to store information of the name of the evaluation index system, establishment time, suitable units and status. The default value of the field "Status" is "not checked". After adding indexes to the index system and assigning weights to each index, the index system can be checked through the system. If the sum of the weights of all indexes of the same index system is 1, then the status is "valid", otherwise the status is "invalid". The index system with the status of " not checked " or "invalid" will not be listed in the list box when assigning the evaluation tasks. The data table "Index" is used to store the index information of an index system. The data table "Task of carbon performance evaluation" is used to store the tasks of carbon performance evaluation, including the information of the task and the objective weight coefficient, subjective weight vector, entropy weight vector, weight vector and evaluation value. The data table "Detail of carbon performance evaluation" is used to store the data of carbon performance evaluation submitted by the evaluated coal mines, which is used as the data source of carbon performance calculation. The data table "Value of carbon performance evaluation" is used to store the value of carbon performance evaluation of the evaluated coal mines.

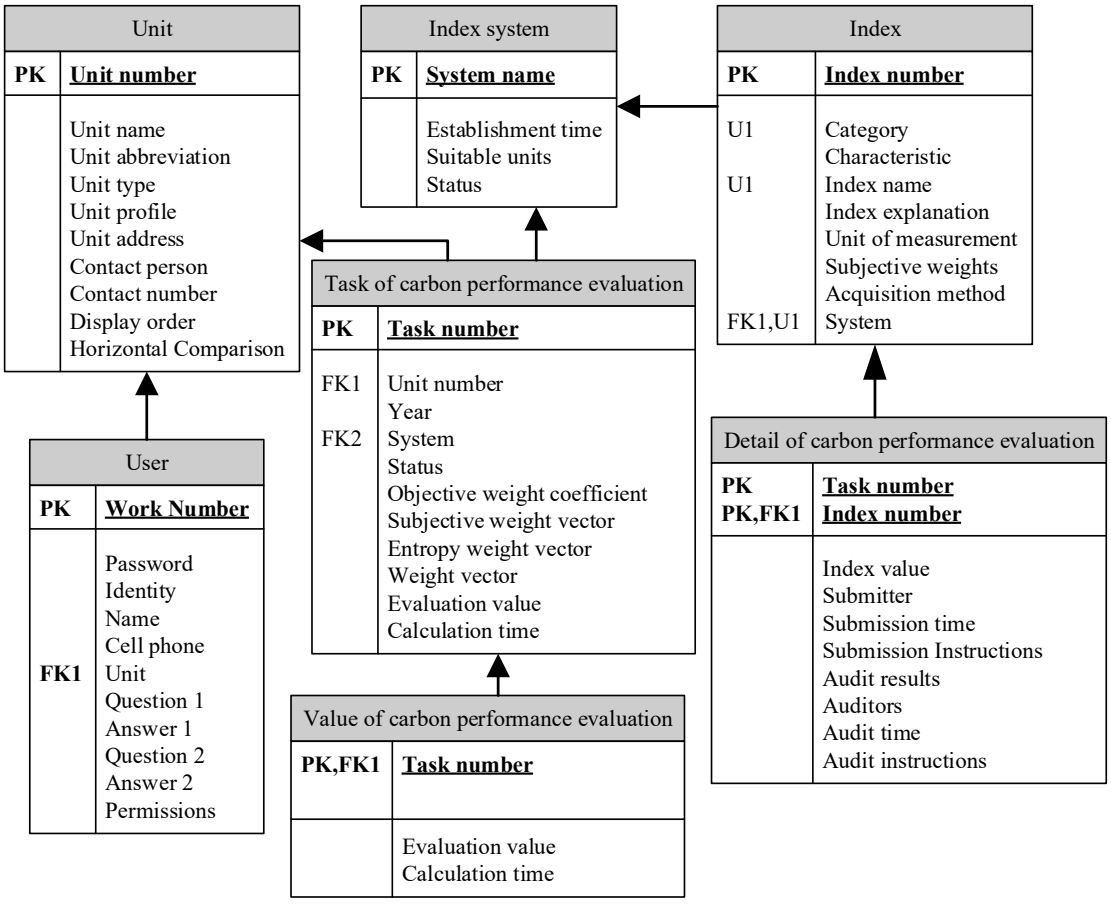


Figure 5. The relationship between the database tables

3.4. Program Design

Taking ASP and C# as the development language, Dreamweaver 8.0 and Visual Studio 2019 as the development platform, an online system of carbon performance evaluation for coal mines owned by the coal industry group is designed.

4. Application Analysis

Coal industry group P is located in Pingdingshan City, Henan Province. The proposed method is applied to evaluate the carbon performance of its 14 coal mines.

The constructed index system of the carbon performance evaluation is shown in Table 1.

The data of 14 coal mines owned by Coal Industry Group P in 2021 are used as an example for calculation. The values of these indexes are shown in Table 2, and the objective weights are obtained by formula (1) ~ (6), as shown in Table 3..

Table 1. The index system of carbon performance evaluation of coal mines

Number	Secondary index name	Characteristic	Unit of measurement	Subjective weights
1	Annual carbon emission	Negative	ton	0.0656
2	Intensity of carbon emission	Negative	tons of CO_2/ ten thousand yuan	0.0719
3	Reduction rate of carbon intensity	Positive	%	0.0569
4	Gas utilization rate	Positive	%	0.0806
5	Annual comprehensive energy consumption	Negative	ten thousand tons of standard coal	0.0650
6	Intensity of energy consumption	Negative	ton of standard coal / ten thousand yuan	0.0750
7	Reduction rate of energy consumption intensity	Positive	%	0.0550
8	Usage rate of green energy	Positive	%	0.0800
9	Yield of annual raw coal	Positive	ten thousand tons	0.1400
10	Annual gross industrial output per capita	Positive	ten thousand yuan	0.1100
11	Annual growth rate of gross industrial output per capita	Positive	%	0.0950
12	Full work efficiency of raw coal	Positive	ten thousand tons	0.1050

Table 2. The index values

Coal Mine / Index	Mine 1	Mine 2	Mine 3	Mine 4	Mine 5	Mine 6	Mine 7
1	596756	452616	33281	545132	325010	228683	359943
2	2.2633	2.5035	0.3870	2.9085	2.1242	0.8433	1.7644
3	0.6274	8.3464	-52.0256	-54.9529	1.0956	2.0482	-2.1697
4	0	0	0	0	6.3382	0	0
5	2.5914	1.7376	0.7251	1.5533	1.2596	1.4782	1.2594
6	0.0983	0.0961	0.0843	0.0829	0.0823	0.0545	0.0617
7	-4.0905	6.3950	-53.4388	-9.7954	1.6772	1.5441	-0.7959
8	0	0	0	0	0	13.4913	0
9	310.2	212.7	101.18	220.5	180	319.03	240
10	31.3408	40.1677	27.8868	33.8679	37.5644	39.9257	64.9061
11	8.2849	17.1392	-28.5973	9.4463	3.8954	7.1273	-1.4576
12	1.1173	1.4320	0.9942	1.2074	1.3392	1.4234	2.3139
Coal Mine / Index	Mine 8	Mine 9	Mine 10	Mine 11	Mine 12	Mine 13	Mine14
1	722726	194817	585792	590392	203959	342693	161359
2	2.7782	2.5466	2.8572	2.4117	2.3072	2.2043	2.1258
3	-73.2594	-4.4193	2.4919	16.5301	6.8582	-10.7973	10.6441
4	0	0	34.0828	0	88.2005	30.2805	0
5	2.4496	0.4592	2.2937	2.5937	1.1146	1.5642	0.4712
6	0.0942	0.0600	0.1119	0.1060	0.1261	0.1006	0.0621
7	-11.3793	-0.2259	-25.1273	9.5199	3.6215	-1.4346	16.3301
8	13.2903	0	0.5140	2.4966	0	20.0672	0
9	306.05	90	241.2	288	104	182.9	89.3
10	34.5796	31.2756	31.6096	37.7079	23.6997	41.3251	44.5975
11	-16.6216	12.1174	-1.7025	12.6953	8.7852	2.6378	15.5445
12	1.2328	1.1150	1.1269	1.3443	0.8449	1.4733	1.5899

Table 3. The objective weights

Index	Objective weights w_o
1	0.0397
2	0.0760
3	0.0272
4	0.3014
5	0.0578
6	0.0339
7	0.0183
8	0.2685
9	0.0637
10	0.0459
11	0.0216
12	0.0459

Table 4. The subjective weights

Index	Subjective weights w_s
1	0.0656
2	0.0719
3	0.0569
4	0.0806
5	0.0650
6	0.0750
7	0.0550
8	0.0800
9	0.1400
10	0.1100
11	0.0950
12	0.1050

Eight experts are invited and the Delphi method is used to obtain the subjective weight of each index, as shown in Table 4.

Let α=0.5. The comprehensive weight of each index is calculated by formula (7), as shown in Table 5.

Let a=50, and b=100. The score of each index of each coal mine is obtained by formula (8) and (9), as shown in Table 6.

The scores of comprehensive evaluation are obtained by formula (10), as shown in Table 7.

Table 5. The comprehensive weights

Index	Comprehensive weights w_c
1	0.0526
2	0.0739
3	0.0420
4	0.1910
5	0.0614
6	0.0544
7	0.0366
8	0.1742
9	0.1019
10	0.0780
11	0.0583
12	0.0755

The data of carbon performance evaluation are submitted by the coal mine evaluators through the system, and audited by the group administrator. The questionable data will be rejected to be corrected until all the data of carbon performance evaluation are approved. Finally, the board of carbon performance of coal mines owned by Coal Industry Group P obtained by calculation is shown in Figure 6. Click the horizontal comparison and vertical comparison buttons in Figure 6 to get the horizontal comparison graph shown in Figure 7 and vertical comparison graph shown in Figure 8, respectively.

From Figure 7, it can be seen that the performance values of the mine 6 and mine 13 in 2021 are relatively good, while they are relatively poor in mine 3, mine 4, mine 8, mine 9 and mine 10. For the coal mines with relatively poor values of carbon performance, the main indexes that produce gaps can be found out from the index values in Table 2, so that the targeted improvement measures can be proposed.

Table 6. The index scores

Coal Mine / Index	Mine 1	Mine 2	Mine 3	Mine 4	Mine 5	Mine 6	Mine 7
1	59.1356	69.5890	100.0000	62.8795	78.8432	85.8290	76.3098
2	62.7950	58.0320	100.0000	50.0000	65.5517	90.9515	72.6865
3	91.1445	95.4429	61.8242	60.1941	91.4052	91.9357	89.5869
4	50.0000	50.0000	50.0000	50.0000	53.5931	50.0000	50.0000
5	50.0555	70.0542	93.7714	74.3713	81.2503	76.1294	81.2557
6	69.4234	70.9407	79.1841	80.1854	80.5677	100.0000	94.9543
7	85.3655	92.8800	50.0000	81.2771	89.4990	89.4036	87.7266
8	50.0000	50.0000	50.0000	50.0000	50.0000	83.6152	50.0000
9	98.0782	76.8576	52.5856	78.5553	69.7406	100.0000	82.7994
10	59.2717	69.9823	55.0806	62.3381	66.8235	69.6887	100.0000
11	90.3203	100.0000	50.0000	91.5900	85.5216	89.0548	79.6696
12	59.2717	69.9823	55.0806	62.3381	66.8235	69.6887	100.0000
Coal Mine / Index	Mine 8	Mine 9	Mine 10	Mine 11	Mine 12	Mine 13	Mine14
1	50.0000	88.2851	59.9308	59.5971	87.6221	77.5608	90.7115
2	52.5846	57.1764	51.0171	59.8511	61.9233	63.9641	65.5207
3	50.0000	88.3342	92.1827	100.0000	94.6142	84.7825	96.7223
4	50.0000	50.0000	69.3212	50.0000	100.0000	67.1657	50.0000
5	53.3770	100.0000	57.0274	50.0000	84.6478	74.1166	99.7178
6	72.3004	96.1500	59.9242	64.0634	50.0000	67.7945	94.7127
7	80.1420	88.1351	70.2895	95.1195	90.8924	87.2689	100.0000
8	83.1144	50.0000	51.2806	56.2207	50.0000	100.0000	50.0000
9	97.1749	50.1524	83.0605	93.2464	53.1994	70.3717	50.0000
10	63.2017	59.1925	59.5979	66.9976	50.0000	71.3867	75.3575
11	63.0921	94.5101	79.4019	95.1419	90.8673	84.1468	98.2567
12	63.2017	59.1925	59.5979	66.9976	50.0000	71.3867	75.3575

Table 7. The scores of comprehensive evaluation

Mine 1	Mine 2	Mine 3	Mine 4	Mine 5	Mine 6	Mine 7
64.1844	66.1956	62.1470	62.6202	66.7896	78.6964	73.2194
Mine 8	Mine 9	Mine 10	Mine 11	Mine 12	Mine 13	Mine14
66.0815	65.1598	64.5550	66.4835	70.6238	77.0995	69.2795

Number	Year	Mine 1	Mine 2	Mine 3	Mine 4	Mine 5	Mine 6	Mine 7	Mine 8	Mine 9	Mine 10	Mine 11	Mine 12	Mine 13	Mine 14	Horizontal comparison
1	2015	67. 6571	68. 8295	71. 344	71. 981	67. 9029	72. 7281	79. 968	60. 0133	64. 7686	69. 94	70. 3053	79. 355	71. 4514	67. 4764	
2	2016	68. 154	61. 353	63. 3459	67. 3829	63. 553	74. 3895	80. 3409	66. 9902	62. 7613	76. 3763	66. 3209	76. 27	62. 0186	67. 0563	
3	2017	60. 6324	60. 6527	66. 3105	76. 0579	58. 0937	68. 6295	69. 6191	63. 1583	62. 7416	63. 7203	60. 1039	68. 4872	61. 1083	64. 9652	
4	2018	67. 4457	63. 5523	65. 2424	75. 8736	64. 9243	74. 2018	73. 1532	70. 8864	64. 2011	71. 8395	65. 7365	76. 2337	55. 3536	67. 5764	
5	2019	63. 1293	61. 951	70. 5544	53. 5975	64. 0601	76. 8667	72. 7467	70. 5062	63. 9575	72. 2162	61. 3192	68. 6262	78. 1774	64. 3355	
6	2020	58. 5274	59. 6417	66. 8508	69. 505	62. 7622	70. 998	66. 475	71. 7224	60. 7692	63. 587	58. 2377	64. 7267	75. 1542	61. 6377	
7	2021	64. 1843	66. 1956	62. 147	62. 6201	66. 7896	78. 6964	73. 2193	66. 0815	65. 1598	64. 555	66. 4835	70. 6238	77. 0995	69. 2795	
Vertical comparison																

Figure 6. The board of carbon performance of coal mines owned by coal industry group P

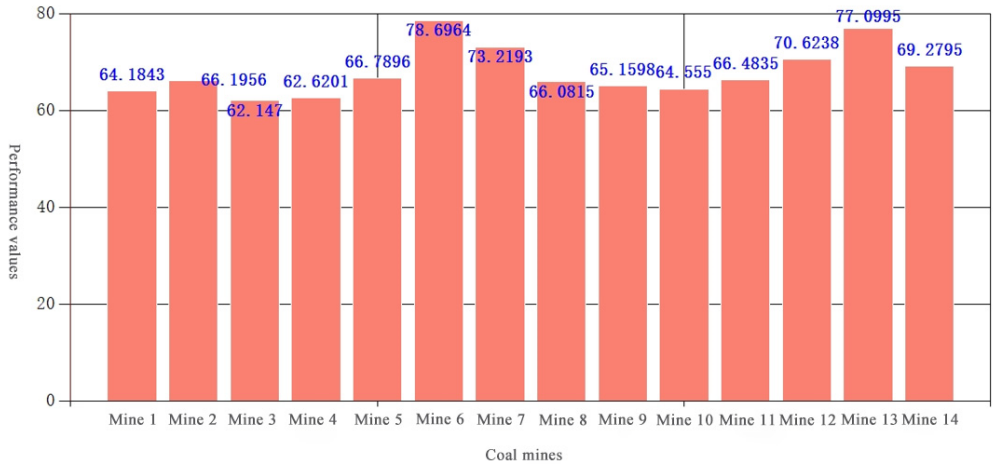


Figure 7. The horizontal comparison of carbon performance of coal mines owned by Coal Industry Group P in 2021

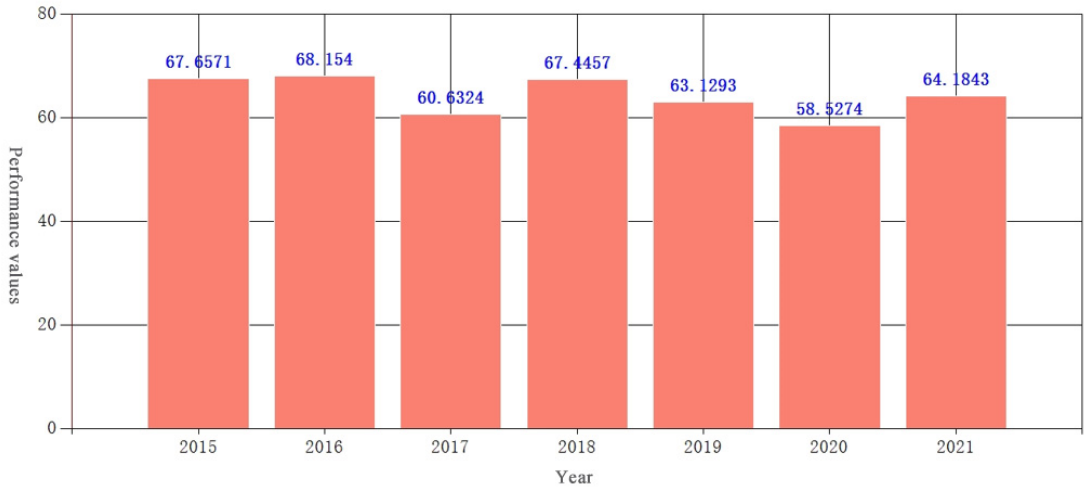


Figure 8. Vertical comparison of carbon performance of Mine 1 owned by Coal Industry Group P in 2015-2021

From Figure 8, it can be seen that the performance values of mine 1 are relatively low in 2017 and 2020. The main reasons for this according to the analysis of its index values in each year are as follows: yield of annual raw coal, annual growth rate of gross industrial output per capita and full work efficiency of raw coal in 2017 are relatively low. The reduction rate of carbon intensity, reduction rate of energy consumption intensity, yield of annual raw coal, annual growth rate of gross industrial output per capita and full work efficiency of raw coal in 2020 are relatively low, while the annual comprehensive energy consumption is relatively high.

5. Conclusion

An online evaluation method for carbon performance of coal mines owned by the coal industry group based on combination of subjective and objective weights is proposed. The proposed method for evaluating the carbon performance of coal mines based on combination of subjective and objective weights takes into account both subjective and objective weights, and the proposed method can complement each other's strengths and make evaluation results more objective. The designed online evaluation system realizes online collection, audit, calculation, result viewing and comparison of carbon performance. The designed online evaluation system encapsulates the complex calculation process of carbon performance evaluation, improving the efficiency of calculation and ensuring the correctness of the calculated results. The evaluation results are presented in the form of a board, which enables horizontal comparison of carbon performance of different coal mines in the same year and vertical comparison of carbon performance of the same coal mine in different years, and is conducive to identifying the focus of improvement.

Acknowledgments

Funding: This work supported by “the Fundamental Research Funds for universities in Henan Province, (SKJZD 2023-01)”.

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