Eco-Cycle Comprehensive Operation Performance Evaluation–A Case Study of Baotou Steel Group

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Abstract. With the advent of circular economy, enterprises have no longer given priority to the economic benefits, but also focus on social responsibility and sustainable development. In order to accelerate the ecological change of enterprise system, every enterprise vigorously carries out green technology innovation and development. Therefore, how to evaluate the performance of ecological cycle has become a problem for management personnel. This paper takes Baotou steel group as an example, which is one of the largest steel companies in China, and establishes an ecological cycle performance evaluation index system from the aspects of economic operation, resource impact control and ecological circulation innovation. Based on that, the entropy-topsis model is used to evaluate the performance of ecological cycle in Baotou steel group. Through the evaluation, we find out that the ecological cycle performance of Baotou steel rose before 2010 and still at the middle and primary stage of its eco-cycle development. The results show the evaluation index system and method can help management personnel to realize the status of their company's eco-cycle development. It also can help policy makers to make better green policies and strategies, promoting the eco-cycle transformation in China.

Keywords: Eco-cycle · Operation performance evaluation · Entropy-topsis

1 Introduction

In recent years, with the transforming of the concept of ecological civilization construction, to realize low carbon development and cycle development has been the important goal of the international economic development, the development and the transformation of the target. The development direction of enterprise has changed from a single to rely on economic benefit as the guidance to the ecological cycle of performance oriented transformation. The evaluation of ecological cycle operating performance has become an important research topic, which

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specifically reflected the enterprise transformation and put forward applicable suggestions for the future development of enterprise.

In the whole performance evaluation, building the evaluation index system is the critical part, reviewing the related literature, a large number of scholars have discussed the different content of the evaluation index system.

Such as the research using the three dynamic indicators including economic growth, environmental improvement and technical features to differentiate the enterprise ecological performance into 13 types including senior evolution to severe degradation [6]. Besides, there are some researches focusing on the circular economy developing standard of industrial park to evaluate, such as constructing the circular economy evaluation index system of industrial park including economic development, resource utilization, pollution control and material recycling indicators and using the TOPSIS method to evaluate [13] and based on AHP and FCE method, through economic development, the material reduction and circulation, pollution control and park management to build comprehensive evaluation model of circular economy of industrial parks [12], also, some researchers are committed to have assessment for the performance of enterprises and industrial parks, such as incorporating research and development (R&D) and marketing policy to build a innovative supply chain performance measurement system [15], to use discounted cash flow (DCF) and multi-attribute global inference of quality (MAGIQ) methods to evaluate the economic, environmental and social performances of eco-industrial park (EIP) pilot project [1], and based on principal component analysis and set pair analysis (SPA) and the fuzzy mathematics method to construct the performance evaluation system [5,8]. In addition, some use Delphi, LCA technique to select indicators to evaluate the green public procurement [14], setting the economic indicator and three generally applicable simplified environmental indicators (raw material consumption, energy consumption, and CO_2 emission) as the eco-efficiency indicators to evaluate the ecology efficiency of EIP [14], using the non-radial DEA model to evaluate the eco-efficiency [10], taking advantage of R cluster and factor analysis to have quantitative selection for indicators to build the green industry evaluation system including three criterion layers of green production, green consumption, and green environment [4], applying data envelopment analysis (DEA) to study the resource efficiency of cities [2], and presenting a compliance-based multidimensional trust evaluation system (CMTES) and also using improved TOPSIS technique to derive trustworthiness from compliance values [9].

Through the above review, a large number of methods such as the entropy-topsis, principal component analysis, gray correlation analysis, AHP and FCE, factor analysis, DEA model, the fuzzy comprehensive evaluation method and other evaluation methods have been widely used in the indicator system.

Based on the circular economy and industrial theory, this article builds the system of ecological cycle operation performance evaluation index and then takes the Baotou steel group as a case study, and analyzes the current eco-cycle operation performance and finally puts forward the corresponding countermeasures and suggestions.

2 Construction of Eco-Cycle Operation Performance System

The evaluation index system should accurately reflect the actual situation of enterprise's production and operation management. The establishment of index system is a key part of the whole ecological cycle operating performance's evaluation. It is essential to select the right index and guarantee the credibility of the results, therefore, this paper combines with the construction principles including system's scientificity and accuracy, effectiveness and comparability, stability and dynamic, operability, combination of qualitative and quantitative and so on, and based on a large number of research results of scholars and the actual work of ecological cycle transformation in enterprises, using analytic hierarchy process and expert-consulting method to select the indicators, builds the eco-cycle operational performance evaluation index system which includes economical operation, resource impact control, technology research and development and eco-cycle innovation. However, based on the performance evaluation of ecological recycling operation of Baotou steel, this research is aimed at finding that there exists missing data of the related index data in development of the technology and pollution control investment and resource compensation at resource impact control layer by collecting concrete data of Baotou steel such as annual report, social responsibility report and so on. Thus considering the actual operation of Baotou steel, we delete the indicators including R & D investment proportion of total amount, the number proportion of R & D in technology research and development level and pollution control investment growth rate and resource compensation fee increase rate in resource impact control layer. The final ecological recycling performance indicators are as follows in Fig. 1.

3 Entropy-Topsis Mode

On the basis of system theory, entropy is an ordered metric reflecting degree of disorder in the system [11]. Therefore, the smaller information entropy is, the lower disorder of information is, and the greater the effect of the information value and the weight information are, and vice versa [7]. Using entropy to reflect the size of information can come to the more objective and fair conclusions. Analytic hierarchy process (AHP) is usually used to determine the weighting factor of evaluation index in TOPSIS method, Because of its strong subjective factors, we use the improved entropy weight method to determine the weight of the evaluation index and to some extent avoid the influence of subjective factors. When the relative importance of evaluation index is difficult to determine, using the weight of entropy calculation index is more reasonable [3].

The general idea for using entropy weight method: To construct the index system and standard weighted matrix, and normalization of the relevant data into the model in the moment. Specific steps are as follows:

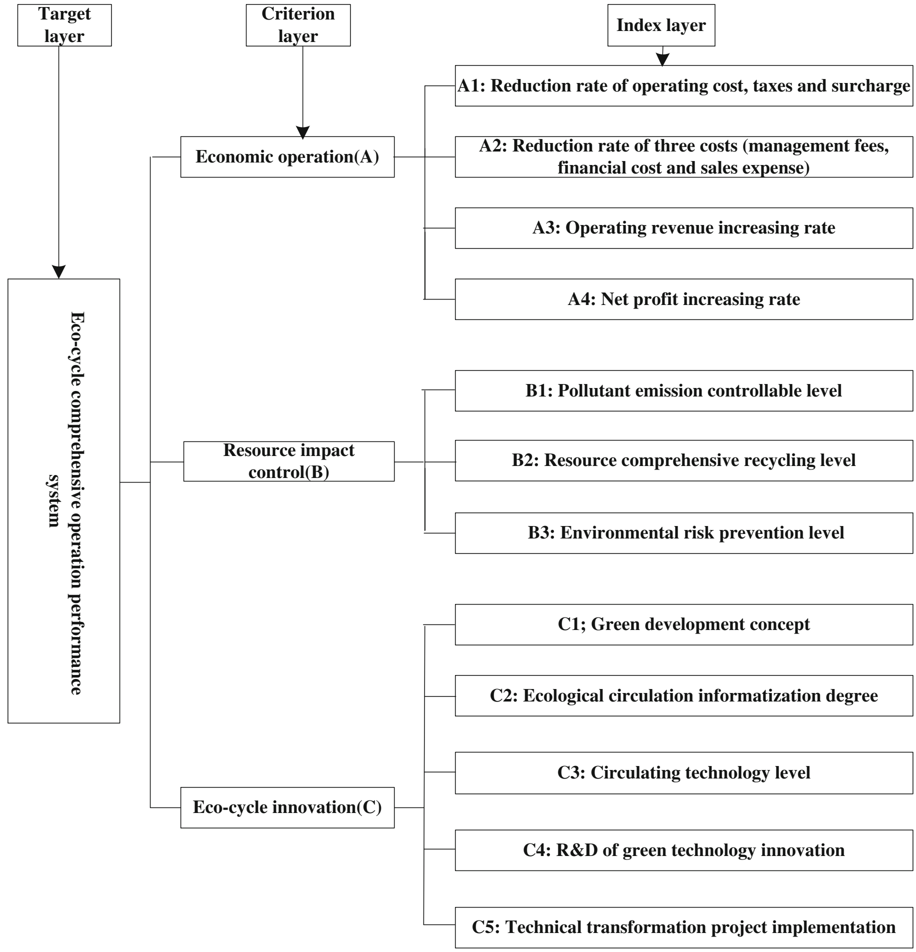

Fig. 1. Eco-cycle comprehensive operation performance system

(1) Data standardization
The evaluation system has n objects to be evaluated, m evaluation indicators, the evaluation matrix is $X = (x_{ab})_{n\times m}$ $(a = 1, 2, \cdots, n;\ b = 1, 2, \cdots, m)$.

For benefit type index:

$$y_{ab} = \frac{x_{ab} - \min x_b}{\max x_b - \min x_b}\ (1 \le a \le n, 1 \le b \le m). \tag{1}$$

For cost type index:

$$y_{ab} = \frac{\max x_b - x_{ab}}{\max x_b - \min x_b}\ (1 \le a \le n, 1 \le b \le m). \tag{2}$$

Normalization:

$$Q_{ab} = \frac{y_{ab}}{\sum_{a=1}^{n} y_{ab}} \ (1 \le a \le n, 1 \le b \le m). \tag{3}$$

(2) Calculation of entropy index

$$P_b = -1/\ln n \sum_{a=1}^{n} Q_{ab} \ln Q_{ab} \ (1 \le b \le m). \tag{4}$$

(3) Determine the index weight

$$\varphi_b = (1 - P_b)/\sum_{b=1}^{m} (1 - P_b), \tag{5}$$

where φ_b satisfies the two conditions $0 \le \varphi_b \le 1$ and $\sum_{b=1}^{m} \varphi_b = 1$:
(4) Standardized weighting matrix is obtained from normalized matrix and index weight.

$$W = (w_{ab})_{n\times m} = (\varphi_b y_{ab})_{n\times m}. \tag{6}$$

(5) Determine the positive and negative ideal solution
Positive ideal explanation imagines each index to achieve the most satisfactory solution, with W^+ and negative ideal solution is to imagine each index to achieve the most satisfactory solution, with W^-.

$$W^+ = \{\max w_{ab}|\, b \in V^+, \min w_{ab}|\, b \in V^-\} = \{w_1^+, w_2^+, \cdots, w_m^+\}, \tag{7}$$
$$W^- = \{\min w_{ab}|\, b \in V^+, \max w_{ab}|\, b \in V^-\} = \{w_1^-, w_2^-, \cdots, w_m^-\}, \tag{8}$$

where V^+= Benefit index set, V^-= Cost index set.

(6) Calculated distance
Each evaluation object to the government ideal sister distance with D_a^+, D_a^-, said, calculated by the following formula:

$$D_a{}^+ = \sqrt{\sum_{b=1}^{m} (w_{ab} - w_b^+)^2} (a = 1, 2, \cdots, n), \tag{9}$$
$$D_a{}^- = \sqrt{\sum_{b=1}^{m} (w_{ab} - w_b^-)^2} (a = 1, 2, \cdots, n). \tag{10}$$

(7) Calculate the relative closeness of each evaluation object

$$H_a = D_a{}^-/(D_a{}^- + D_a{}^+)(a = 1, 2, \cdots, n), \tag{11}$$

where H_a is the a object and how close the solution to, the value of H_a is between 0 and 1, the larger the value of H_a, the smaller the distance between the evaluation object and the positive ideal solution, the greater the distance from the negative ideal solution, the closer to the optimal level.

4 Case Study

Baotou steel group (hereinafter referred to as Baotou steel) is one of the earliest construction of iron and steel industrial bases after the founding of the People's Republic of China, it was first constructed in 1954 and was put into production in 1957. Turned into a corporate enterprise in 1998, it is the most important iron and steel industrial base and the largest rare earth industrial base in China, and one of the biggest rare earth scientific research and production bases as well. Always committed to diversify development, except to the major business of steel and rare earth, it also owns the mining and the steel industry. During the "twelfth five-year"? "big steel"? will be built and commit to become the world's largest production base of rare earth steel and the most competitive rare earth production and scientific research unit and its annual sales revenue will reach more than 100 billion yuan. By 2015, the group's total assets have amounted to 144.9 billion yuan, 33459 people have been employed and 22.501 billion yuan of sales income has been achieved. At present, Baotou steel has entered the ranks of tens of millions of tons of iron and steel enterprises in China, and has an important influence in the world. In recent ten years, Baotou steel has been committing to adhere to lead innovation, promoting the ecological cycle transformation and upgrading, keeping the environmental protection concept and setting the image of green development. Therefore, based on the practical situation of Baotou steel, evaluating its performance helps to future development selection and strategic decision-making.

(1) Data selection
According to the availability of data, this paper selects Baotou steel annual reports during the ten years from 2006 to 2015, part of the data are obtained by calculations, and others are obtained by the expert scoring method.

(2) Empirical results
In the process of analyzing of the index data, in order to eliminate the influence of dimension to the data, we use the formulas (1) and (2) to get the standardized data shown in Table 1, then take use of formula (3) to give normalized treatment to the data and finally get the weight P and the entropy ϕ.

As is shown in Table 2, the weight of the indicators for economic operation ranges between 0.02 and 0.033, the weight of the indicators for resource impact control is weighted between 0.06 and 0.12, the weight of the indicators for ecological circulation innovation range between 0.04 and 0.132. Therefore, the indicators of resource impact control have a great effect on the ecological cycle performance of Baotou steel.

Most of the indicators are at a low level, comprehensive index of ten years in a similar seven years posted schedule H below the 0.1 level. But it had a great reversal in 2010, whose comprehensive value of H reached the level of 0.04607, the value of H for economic operation even reached at 0.7 or so, and the value of H for resource impact control and the ecological circulation innovation were also at a high stage the ten years (Table 3).

Table 1. Standardized data

Year	A1	A2	A3	A4	B1	B2
2006	0.1107	0	0.0397	0.0911	0.1048	0.1347
2007	0.1159	0.1197	0.0007	0.0902	0.2048	0.1347
2008	0.1071	0.1112	0.0552	0.089	0.1476	0.1796
2009	0.1117	0.1118	0.0322	0.0866	0.1667	0.1856
2010	0	0.0913	0.7332	0.121	0.119	0.2156
2011	0.1103	0.1126	0	0.1401	0.1571	0.0749
2012	0.1109	0.119	0.0383	0.0949	0	0.0449
2013	0.1108	0.1041	0.0389	0.0905	0.0524	0.015
2014	0.1116	0.1147	0.0351	0.1967	0.0476	0.015
2015	0.111	0.1156	0.0268	0	0	0
Year	B3	C1	C2	C3	C4	C5
2006	0.0435	0.1019	0	0.1327	0.142	0.1393
2007	0	0.1019	0.1135	0.1467	0.1514	0.1333
2008	0	0	0.0054	0.1234	0.142	0.1274
2009	0.3913	0.051	0.0054	0.1292	0.0978	0.1298
2010	0.087	0.1911	0.1135	0.1467	0.142	0.1262
2011	0.0435	0.2229	0.2054	0.1257	0.1293	0.119
2012	0.0435	0.0127	0.1946	0.1118	0.142	0.1298
2013	0.1304	0.1274	0.1135	0.0012	0.041	0.0012
2014	0.1304	0.0637	0.1243	0	0.0126	0
2015	0.1304	0.1274	0.1243	0.0827	0	0.094

Table 2. Entropy weights of indicators

Item	Indicator	P	φ
Economical operation	A1	0.9542	0.0231
	A2	0.953	0.0236
	A3	0.4763	0.2634
	A4	0.9355	0.0325
Resource impact control	B1	0.8624	0.0692
	B2	0.8474	0.0768
	B3	0.7755	0.1129
Eco-cycle innovation	C1	0.765	0.1182
	C2	0.7384	0.1316
	C3	0.9004	0.0501
	C4	0.9	0.0503
	C5	0.9036	0.0485

Table 3. The closeness of the evaluation objects and the positive ideal solution

Year	Comprehensive operation		Economic operation		Resource impact control		Eco-cycle innovation	
	H	Rank	H	Rank	H	Rank	H	Rank
2006	0.0658	10	0.0417	6	0.0876	8	0.0839	8
2007	0.0773	5	0.018	10	0.1099	3	0.116	5
2008	0.0686	9	0.057	2	0.1077	4	0.0557	10
2009	0.1295	2	0.0361	7	0.3043	1	0.0596	9
2010	0.4607	1	0.7017	1	0.135	2	0.1497	2
2011	0.1093	3	0.0215	9	0.0854	9	0.1988	1
2012	0.0819	4	0.0418	5	0.039	10	0.1379	3
2013	0.0769	6	0.042	4	0.0979	5	0.1073	6
2014	0.071	8	0.044	3	0.0973	6	0.0904	7
2015	0.0765	7	0.0298	8	0.0936	7	0.1167	4

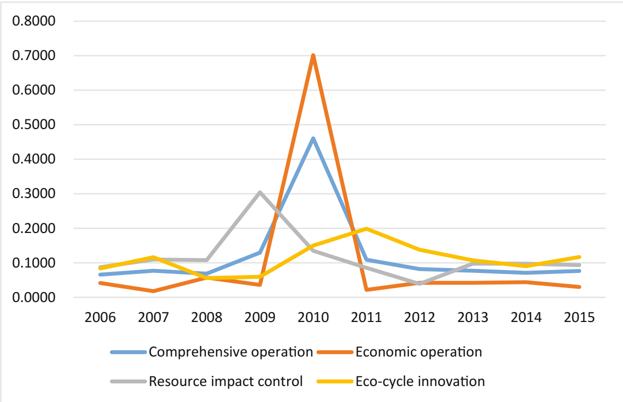

Fig. 2. The trend of closeness of each evaluation object and positive ideal solution

In order to reflect the current operating state of Baotou steel more intuitively and clearly, we make a brief line chart, it shown in Fig. 2.

The chart can reflect the development status of the last few years clearly and objectively, and combining with the specific content from annual report of Baotou steel, the following conclusions can be reached.

Baotou steel's comprehensive performance is at huge ups and downs. From 2006 to 2009, the overall ecological cycle operation of Baotou lagged behind slightly, but still grew steadily. But in the year of 2010, the business of Baotou steel had a great leap forward trend. The value of H rose from about 0.1 in 2009 to nearly 0.5. For Baotou steel, the year of 2010 is not only glorious, but also a sharp peak of development. The ecological cycle is good, which is the result of continuous accumulation. However, after 2010, Baotou steel business, abruptly suffered a great depression. In 2011, the value of H straightly dropped to about 0.05, and then was continuously declining during 2012, and was in a state between 0.05 and 0.1 from 2012 to 2015. So it's obvious to see that after Baotou steel's ecological cycle operates to a certain stage, the development of the operation will slow down, the challenge of industrial upgrading will increase.

As the same as the composite index, there also existed a parabola change trend for economic operation. The value of H reached 0.7 in 2010, but years after that it stayed between 0.01 and 0.057, which is similar to the analysis in (1). To be brief, Baotou steel business was in a condition of lower stage at first, but later went through such a huge revolution in 2010 and showed a trend of rapid increase. Thus it can be said that the year of 2010 is an important turning point in Baotou. Meanwhile, at the annual report. In previous years, Baotou steel has been committing to the construction of R & D center, and by the time of 2010, R & D center has been building more perfect. So it is not hard to explain before 2010, Baotou economy gradually increased, to show the reason for the substantial increase in 2010, and after a few years, Baotou research devoted to technology, may it lead to the decline in corporate profits.

Ecological circulation doesn't grow as such amazing speed as economic operation, but takes on a smooth curve of innovation. It presents a substantial increase in 2009 to 2011, makes a breakthrough in 2011, and gradually decline after 2011, finally is under the stable state. In general, compared with the 2000s, the ecological circulation innovation level in 2010s goes up. However, in comparison with the former two kinds of curve, the ecological circulation innovation reaches peak in 2011, but the economic performance and the comprehensive ecological cycle performance is relatively weak. Through the phenomenon and combining with the annual report of Baotou steel, during 2009 to 2011, Baotou steel has been promoting science and technology innovation and green development, introducing the resources recycling project to have an ecological cycle transformation, which leads to decline in the economic benefits. And then shows a trend of decline of ecological circulation innovation, it can draw that when ecological circulation innovation to achieve in a certain state, the growing rate slows down and breakthroughs are much more difficult to realize.

The trend of resource impact control is different from the former three. Through the line chart, we can clearly see that the sharp change of resource impact control is 2009 rather than 2010 or 2011, so, it appeared earlier than the year of vast change, and it can be seen in the line changes, the resource control increased in the previous year, then it would lead to eco-cycle comprehensive performance rising the next year, in the same way, when the resource impact control had a downward trend, after a year it would lead to a decline in the economic operation and eco-cycle comprehensive performance. Thus we can speculate that resource impact control is the foundation of ecological cycle of enterprise innovation and the daily basic implementation of enterprise resource recycling also determines the enterprise's operation and development.

Besides, usually, we can divide the H into five levels, lower stage ($N < 0.2$), primary stage ($0.2 \leq N < 0.4$), middle stage ($0.4 \leq N < 0.6$), relatively advanced stage ($0.6 \leq N < 0.8$), and advanced stage ($0.8 \leq N < 1.0$). So it's obvious to come out that the highest H values 0.46, the eco-cycle development of Baotou steel is in the middle and primary stage. Therefore, we can draw the conclusion that before 2010, the performance of Baotou steel's ecological cycling operation increased slowly, until 2010, the ecological cycle achieved a good level, but after 2010, industry innovation tended to be slow gradually, Baotou group operating performance gradually tumbled and the eco-cycle development of Baotou steel is in the middle and primary stage.

5 Conclusion

In view of the above empirical results, we conclude that the ecological performance of Baotou Steel rose in 2010, reached a peak in 2010, then decreased gradually, and the eco-cycle development of Baotou steel is in the middle and primary stage. And in the case of data support analysis, we confirm the reliability of the conclusion. So based on the conclusion of Baotou Steel Company, some suggestions are purposed as follows:

(1) Increase resource recycling and sustainable development. In the above analysis we can clearly observe the resource control impact indicator is the cornerstone of enterprise ecological cycle operation. Benign circulation of resources under the guidance of national policy is conducive to the development of enterprises. In the indexes we studied we can also know that controlling pollutant emissions, building chain impact prevention level, achieving effective material use and effective cycle are the measures to promote the development of enterprise resources. Of course, we can also through other ways such as optimization of industry leading and the construction of new production lines and other methods to improve the level of corporate resources impact control.

(2) Increase investment in green technology research and development. Drawn from the above analysis, eco-cycle innovation plays an important role in the eco-cycle comprehensive development of enterprises, so the ecological cycle innovation as a part of leading enterprise development is greatly important and cannot be ignored, therefore, increasing investment in green technology research and development is very important. The policy of the country now is to encourage the development of green industry and environmental protection enterprises, only to meet the mainstream trend is the real development, and Baotou as a high energy consumption and high pollution steel enterprise, designing and creating for the theme of environmental protection industry chain is the priority among priorities of Technology in recent years.

(3) Improve the energy structure. Increasing the recycling of resources and investment in green technology research and development are currently the most urgent task and measures based on the current. And for the future development of ten years, Baotou Steel Company should start in the long run, improve the energy structure of enterprise, deepen the reform and build

a green enterprise whose development conforms to the trend of the times. This is also the most useful measure in the future development.

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References

1. Chan FTS, Nayak A et al (2014) An innovative supply chain performance measurement system incorporating research and development (r & d) and marketing policy. Comput Ind Eng 69(1):64–70
2. Deilmann C, Lehmann I et al (2016) Data envelopment analysis of cities-investigation of the ecological and economic efficiency of cities using a benchmarking concept from production management. Ecol Ind 67:798–806
3. Dong J (2010) Analysis of external environment of transmission project based on improved entropy topsis method. Water Resour Power 3:152–154 (in Chinese)
4. Gongrong C, Yanghong D (2016) Performance evaluation of eco-industrial park based on the fuzzy mathematics method. J Hunan Univ Sci Technol 19:82–89
5. Jung S, Dodbiba G et al (2013) A novel approach for evaluating the performance of eco-industrial park pilot projects. J Cleaner Prod 39(5):50–59
6. Li P, Ren H, Zhao L (2005) Evaluation and analysis of enterprise eco-industrialization based on dynamic indicators. Quant Technica Econ 22(12):16–24
7. Mavi RK, Goh M, Mavi NK (2016) Supplier selection with shannon entropy and fuzzy topsis in the context of supply chain risk management. Procedia Soc Behav Sci 235:216–225
8. Rashidi K, Saen RF (2015) Measuring eco-efficiency based on green indicators and potentials in energy saving and undesirable output abatement. Energy Econ 50:18–26
9. Singh S, Sidhu J (2016) Compliance-based multi-dimensional trust evaluation system for determining trustworthiness of cloud service providers. Future Gener Comput Syst 67:109–132
10. Song X, Shen J (2015) The ecological performance of eco-industrial parks in shandong based on principal component analysis and set pair analysis. Resour Sci 37:546–554 (in Chinese)
11. Swendsen RH (2016) The definition of the thermodynamic entropy in statistical mechanics. Phys A Stat Mech Appl 467:67–73
12. Tarantini M, Loprieno AD, Porta PL (2011) A life cycle approach to green public procurement of building materials and elements: a case study on windows. Energy 36(5):2473–2482
13. Wu XQ, Wang Y et al (2008) Evaluation of circular economy development in industrial park based on eco-efficiency theory and topsis approach. Chin J Ecol 27(12):2203–2208
14. Ying Z, Hongzhi W, Guotai C (2016) Construction and application of green industry evaluation indicator system based on factor analysis. J Syst Manag 25:338–352
15. Yan L (2012) Assessment of circular economy in chlorine-alkali chemical industrial parks based on ahp-fce. Ind Technol Econ 31:151–155