Evaluation index system of steel industry sustainable development based on entropy method and topsis method

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Abstract: Sustainable development is the only way for the development of human society. As an important part of the national economy, the steel industry is an energy-intensive industry and needs to go further for sustainable development. In this paper, we use entropy method and Topsis method to evaluate the development of China's steel industry during the "12th Five-Year Plan" from four aspects: resource utilization efficiency, main energy and material consumption, pollution status and resource reuse rate. And we also put forward some suggestions for the development of China’s steel industry.

1. Introduction

As a well-defined concept, sustainable development was put forward in the report of the World Commission on Environment and Development in 1987, "Our Common Future," which means meeting the needs of the present without satisfying its future generations. The capacity needed constitutes a compromise that must be applied in the process of human economic and social development. Once upon a time, we believe that resources are inexhaustible, however only after a few decades we find that many of our resources are running out of steam. Humankind has made advanced use of future generations’ resource because of resources shortage and crazy human desires [1].

As a kind of energy-intensive industries for the steel industry, its consumption in energy and resource is huge. In the process of production, the final steel products and other by-products can be produced through the continuous operation of multi-stage process of coking, sintering, ironmaking, continuous casting, steelmaking and rolling [2]. However, whether it is coking, sintering, ironmaking or continuous casting, steelmaking, rolling, each process must be heated, cooled and repeated operations. However, there is still a big gap both in technology and equipment between our country's steel enterprises and the developed countries', and the overall competitiveness of the steel enterprises is not strong. In particular, there are major problems in terms of resource utilization, pollution status, etc. According to the data, the total energy consumption of China's steel industry accounts for 14.7% of the total energy consumption in the country while the contribution rate to GDP is less than 4%, industrial wastewater discharge accounts for 8.5% of industrial emissions, and industrial dust emission accounts for 15.2% of total industrial emissions % [3]. Therefore, we can find that the steel industry not only consumes a huge amount of resources, but also is a major pollutant discharge. However, as an important part of the national economy, it needs to develop. Besides, the energy saving and emission reduction reform of the steel industry is imminent. Require the steel industry to increase technological upgrading and structural optimization work, change the mode of growth, and strive to enhance the efficiency of the steel industry, and promote China's steel industry to power change. In today's situation, Wang Shuang believes that the major problems in the development of China's steel industry
are the high costs and the low profitability [4]. The pressure on environmental protection is increasing. Yang Donghua proposed the future competition of steel production is mainly the competition of technology and environment. The technology is the basis of all competition [5]. To improve the competitiveness of the steel industry, we must first solve the clean production technology and development issues in the steel industry. Saving energy and reducing emissions in the iron and steel industry are the key points to improve the efficiency of the iron and steel industry.

Through the establishment of evaluation index system to further research on China's steel industry and take the road of sustainable development achievements and defects, monitoring the development of steel industry, strengthening the restructuring of the steel industry, solving the overcapacity in the steel industry fundamentally, the development of gift problems, to make such an energy intensive industry to achieve sustainable development. At the same time, the improvement of the utilization of resources will make the efficiency of the steel industry greatly improved. Wang Jiali said that waste recycling is an important way for iron and steel enterprises to protect environment and reuse resources. In this process, the undesirable output of waste gas and waste residue will reduce profits, so we must reduce the production of undesirable output [6]. To establish the evaluation index system of the steel industry, Han Fengqin proposed should be based on the evaluation index system of national sustainable economy as the basic framework, combined with industry production, process, technology etc., and appropriately increase the resource utilization rate, the proportion of recycling resources [7]. Chen Guokang put forward the following four principles for establishing iron and steel industry evaluation index system: scientific and reasonable, systematic and standardized, widely comparable and operable [8].

2. Construction of Evaluating Model of Comprehensive Index from 2011 to 2015 Based on Entropy Method and TOPSIS Method

2.1. Choice of Entropy Method and Topsis Method

The most primary key task in constructing the multi-index evaluation model is to objectively determine the weight of each index. But there was strong subjectivity and impracticality in above mentioned multi-index evaluation model by Analytical Hierarchy Process (AHP). Therefore, some subjective bias effect caused by AHP could be avoided through adopting objective entropy method with objective accurate weight. Based on the basic principle of information theory, information and entropy are measure of system order and disorder, respectively. If the entropy of the index is smaller, the greater amount of information of the index will be provided in the system accordingly. So, the higher weight of this index should be used in comprehensive evaluation.

The Topsis (Technique for Order Preference by Similarity to an Ideal Solution) method was first proposed by CL Hwang and K. Yoon in 1981, which was ranked the relative merits according to the approximate degree of the finite evaluation object and the idealized target. Thus, the Topsis method is a sort method that approximates the ideal solution, which only requires the utility functions possessing monotonically increasing (or decreasing) properties. The Topsis method is a commonly used and effective method in multi-objective decision-making analysis, also known as the method of separation of advantages and disadvantages. The Topsis method also has the following advantages: no strict control for data distribution, sample size and indicators, uncomplicated mathematical calculations, extensive application range, intuitive geometric meaning, making full use of raw data and less information loss.

2.2. Construction of Entropy Method and Topsis Method

2.2.1 Determine the Weight of Each Index by Entropy Weight Method. There are $m$ evaluation year plan, $n$ evaluation indicators, and each evaluation year evaluation index value form a multi-objective
decision matrix \( X \), \( X_{ij} \) which is the index value of the No. \( j \) indicator of the No. \( i \) alternative. Matrix \( X \) is dimensionless into a matrix \( Y_{ij} = (y_{ij})_{m \times n} \) among

\[
y_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}
\]

The entropy of No.\( j \) index can be defined as

\[
H_j = -K \sum_{i=1}^{n} y_{ij} \ln y_{ij} (j = 1, 2, \cdots, n)
\]

among

\[
K = \frac{1}{\ln n}
\]

The No.\( j \) indicator of the coefficient of difference of \( h_j \), can be expressed as

\[
h_j = 1 - H_j
\]

Let \( \omega_j \) be the weight of No.\( j \) indicator, then

\[
\omega_j = \frac{h_j}{\sum_{j=1}^{n} h_j}
\]

2.2.2 Judge the Closeness of Each Year and Ideal Solution By the Topsis Method. (1) Building an Initialization decision matrix:

The decision matrix \( X \) for each alternative can be expressed as

\[
X = \begin{bmatrix}
x_{11} & \cdots & x_{1n} \\
\vdots & \ddots & \vdots \\
x_{m1} & \cdots & x_{mn}
\end{bmatrix}
\]

(2) Dimensionless decision matrix: Due to the different dimensions of each evaluation index, the initial value is not comparable, so the index is handled dimensionless, the dimensionless matrix can be expressed as

\[
Y_{ij} = (y_{ij})_{m \times n}
\]

(3) Building a Weighted Decision Matrix: Weights of the various indicators as determined by the entropy method \( \omega_j \), multiplying them by a dimensionless matrix \( Y_{ij} \) yields a weight matrix \( V = (v_{ij})_{m \times n} \) among

\[
v_{ij} = \omega_j \times y_{ij} (i = 1, 2, 3, \cdots, m, j = 1, 2, 3, \cdots, n)
\]

Determine the ideal solution and negative ideal solution of each index

The ideal solution of each index can be expressed as
Negative ideal solution can be expressed as
\[
    v^- = \left \{ \begin{array}{l}
    \max_{i=1,2,3,\ldots, n} v_{ij} \quad (i = 1,2,3,\ldots, m; j = 1,2,3,\ldots, n) \\
    \min_{i=1,2,3,\ldots, n} v_{ij} \quad (i = 1,2,3,\ldots, m; j = 1,2,3,\ldots, n)
\end{array} \right.
\]

(7)

For the larger the better indicator

(8)

For the smaller the better indicator

(5) Calculate the distance between ideal solution and negative solution in each year of 2011-2015.

The distance between the value of each year and the ideal solution is
\[
    D^*_i = \left( \sum_{j=1}^{n} (v_{ij} - v^+_j)^2 \right)^{1/2}, \quad (i = 1,2,3,\ldots, m)
\]

(9)

(6) Calculate the closeness between the value of each year 2011-2015 and the ideal solution.

The relative closeness between the ideal solution and the negative ideal solution in each year is
\[
    \xi_i = \frac{D^-_i}{D^*_i + D^-_i}
\]

2.3. Construction of Evaluation Index System

For the evaluation index system architecture, we refer the paper of Chen Yong "steel recycling economy development level evaluation index system construction and application"[9].

Combined with our understanding for the sustainable development of the steel industry, we conduct the study from 14 four-level indicators including the following four dimensions: resource utilization efficiency, major energy and material consumption, pollution status and resource reuse rate.

Table 1. The framework of steel industry sustainable development level indicator system

| Level 1 indicator | Level 2 indicator | Level 3 indicator | Level 4 indicator |
|-------------------|-------------------|-------------------|-------------------|
| Comprehensive utilization of resources efficiency output rates indicators | Resource input and output rates efficiency | Unit investment sales value | Unit investment sales value |
| The level of sustainable development of steel enterprises indicators | The main energy consumption Steel production energy and consumption indicators level indicators | Ton of steel Energy consumption: new water, | Ton of steel energy consumption: kg of standard coal equivalent, |
| | | Total energy consumption, | Comparable energy consumption per ton of steel |
| | | Exhaust gas treatment rate, | Effluent discharge |
| | | Chemical oxygen demand, | Sulfur dioxide emissions |
| | | Emissions pollution indicators | Water pollution indicators |
3. Empirical analysis

3.1. The source and process of data.
During the empirical analysis, the data of source is very important. All of the data are from the official sectors. The data of ton of steel Energy consumption: new water, ton of steel Energy consumption: kilogram of standard coal equivalent, sulfur dioxide emissions, smoke dust emissions, effluent discharge, chemical oxygen demand, total energy consumption come from Wande database. And that of comparable energy consumption per ton of steel, water reuse, exhaust gas treatment rate, dust utilization, waste utilization, the unit industrial sales output value of the current price, the change of steel industry to complete investment, Coke oven gas utilization, converter gas recovery come from the steel Statistical Yearbook. The unit investment sale value is the ratio of the industrial sales output value of the current price and the change of steel industry to complete investment. For the value data which will be affected by inflation, we use the price index of the black metal ore selection industry in the National Bureau of Statistics of 2011.

3.2. Empirical research results and analysis.
Due to the dimension difference of each data, we have a dimensionless process to eliminate the unit difference of the index. Putting the original data into (1) in order to get standardization data, then use the entropy weight method to determine the objective power of each index and get the table 1. According to the data, we can see that in all indicators, the proportion of the unit investment sales value is 0.0763 percent, and the other indicators fluctuate around 0.0665. The unit investment sales value taking up a larger proportion, suggests that the entropy of information is smaller, providing a larger amount of information and making a larger role in the overall evaluation.

| Table 2. Indicator weights obtained by entropy method |
|-----------------------------------------------|
| **Level 2 indicator**                      | **Weights** | **Level 4 indicator** | **Weights** |
| Comprehensive utilization of resources efficiency indicators | 0.0775 | Unit investment sales value | 0.0763 |
| The main energy consumption and consumption level indicators | 0.2634 | Ton of steel energy consumption: new water | 0.0658 |
| | | Ton of steel energy consumption: kg of standard coal equivalent | 0.0657 |
| | | Total energy consumption | 0.0659 |
| | | Comparable energy consumption per ton of steel | 0.0658 |
| | | Effluent discharge | 0.0663 |
| Pollution status indicators | 0.3311 | Chemical oxygen demand | 0.0661 |
Combining the Topsis to calculate the closeness degree. The calculation results should be between 0 and 1. If the result is closing to 1, then the result will be closer to the ideal solution. In this paper, the degree of the level 1 indicator index to the ideal solution increase from 0.2544 to 0.8121 between 2011 and 2015, the result has been approaching to 1. It shows that the level of sustainable development of steel enterprises has been improving as shown in table 2. In the same way, we can get table 3 for the main energy consumption level, pollution condition, resource utilization. Then combine the entropy weight method and Topsis to calculate and analysis. However, in this way, the weights of the index of pollution and the utilization of resources are negative, mainly due to the entropy calculation process (2). N is the number of indicators, which will be adjusted to 4, which is equivalent to the same amount of data that the level 2 indicator corresponds to, and does not affect the final result. According to the data from the table, we can see that the three secondary indexes are improved, and the improvement of the pollution status index is the most prominent, which indicates that the energy consumption level of the steel industry has declined during the twelfth five-year-plan. The effect of pollution control has made good progress, and the utilization rate of resources has been improved.

The improvement of industry's sustainable development is closely related to national policy. In “Comprehensive working plan of energy conservation and emission reduction in the twelfth five-year-plan”, government come up with the price, finance, taxation and finance four aspects of the economic policy conducive to energy conservation and emission reduction.

In the aspect of price, the price reform of resource products should be deepened and the price relationship between coal, electricity, oil, water and gas should be straightened out. The steel industry mainly involved in coal and electricity, and the government will impose punitive prices when the usage of resources over certain standards, and the ultimate purpose of the enterprise is to obtain profits. Therefore, the enterprises will save the applicable resources and make innovation under the promotion of the policies, using new technology to improve the utilization of resources. In terms of fiscal policy, the state has increased the investment of the central budget and the central government's special funds for energy conservation and emission reduction, and the steel industry is a heavy polluter. During the period of twelfth five-year-plan, the pollution treatment has been greatly improved, and the increase of various investment and special funds have made the steel enterprises put more energy into the control of pollution. The level of pollution control has been improved, and there are certain rewards and punishments and policies for the firms. In “Focus on energy conservation management measures”, people's governments at all levels have made remarkable achievements in energy conservation management and technology. This can give the enterprise a certain constraint, and also can promote the deepen the reform, and then promote the entire steel industry reform, and improve competitiveness of the steel industry in the international market.

As for taxation, implement preferential policies of the state to support energy conservation and reduction of income tax and vat, and to promote the reform of resources and taxes, the preferential policies of taxation can give the enterprises a greater impetus. In terms of financial policy, increasing the credit support of various financial institutions and encourage the innovation of financial institutions to be suitable for the credit management model of energy saving and emission reduction.

| Resource reuse indicators          | Exhaust gas treatment rate | Sulfur dioxide emissions | Smoke dust emissions | Coke oven gas utilization | Converter gas recovery | Water reuse       | Dust utilization | Waste utilization |
|-----------------------------------|---------------------------|-------------------------|---------------------|--------------------------|------------------------|------------------|----------------|------------------|
|                                   |                           |                         |                     |                          |                        | 0.3289           | 0.0657         | 0.0658           |
projects. The amount of funds needed for the operation of the steel industry is large, and in the trend of the decline of economic development, the policy can effectively solve the problem of financing and help the industry to accelerate the pace of energy conservation and emission reduction reform. In this process, the threshold of high-energy consumption and high emission industry will be increased, and the information of enterprise environment is included in the information disclosure system of the people's bank. So high-energy consumption enterprises will need to be reformed passively, only by reforming, can the implementation of energy-saving and emission reduction have a broader word. And the increase of resource utilization is mainly the essence of the enterprise's pursuit of profit. When the development of the steel industry is faced with problems, the profit ability decreases, and enterprises will increase profits from various channels. Recycling has both responded to the call of the state and can raise profits, so why not. Therefore, in the period of twelfth five-year-plan, the rate of resource reuse’s closeness degree to ideal solution is also greatly improved.

| Table 3. The Closeness between the Index of Sustainable Development of Iron and Steel Enterprises and the Ideal Solution |
|---|---|---|---|---|---|
| Indicator | Stick with the ideal solution | 2011 | 2012 | 2013 | 2014 |
| The closeness between the index of sustainable development of steel enterprises and the deal solution | | 0.2534 | 0.2862 | 0.4861 | 0.5751 | 0.8120 |

| Table 4. The closeness between the second level indicator and the ideal solution |
|---|---|---|---|---|---|
| Two indicators | Stick with the ideal solution | 2011 | 2012 | 2013 | 2014 |
| The main energy consumption and consumption level indicators | | 0.0237 | 0.0039 | 0.4121 | 0.3517 | 0.6224 |
| Pollution status indicators | | 0.0065 | 0.3639 | 0.5047 | 0.6379 | 0.9264 |
| Resource reuse indicators | | 0.0472 | 0.0425 | 0.4618 | 0.5237 | 0.8743 |

4. Conclusions and suggestions
The empirical research results show that the sustainable development of the steel industry in the period of twelfth five-year-plan reveals a good trend of gradual improvement. And this is closely related to the low-carbon environmental policy made by our country. The steel industry is a high-energy and high-pollution industry. Since the reform of the supply-side structure, the trend of sustainable development has been improved, but the pollution of energy consumption is still severe. Based on the study of the steel industry, we put forward the following suggestions: ① In order to improve the pollution situation as soon as possible, China should implement the policy of protecting the environment as soon as possible. But how to seek the balance between maximize short-term benefits and the environmental protection is a serious problem that government departments should consider carefully. ② It should accelerate the combination of high-technology and iron-steel industry, deepen and create more industrial value-added products. The supply side reform of the steel industry is not required to produce less production, and the excess production capacity mainly refers to low-end steel production capacity and high-end steel is still dependent on the country's import. China's high-end
steel production and the rate of finished products are relatively low and there is still a lot of development space, but it need to focus on the capital and technology for key enterprises to invest in research and development. The steel industry is a high energy consumption and high pollution industry which has more restrictions on improving energy efficiency. However, there is a great improvement in the circulation of emissions, as well as in emissions of waste water, waste gas and dust. We should increase the emphasis on waste disposal to reduce environmental pollution.

The shortage of this article: ① Use the entropy weight method to determine the weight. The weight of indexes will change with the sample, and the amount of power is much more dependent on the sample, and there is a lack of comparison to each index. ② The source of the data is the statistical yearbook which has data update delay and can’t contact with the current market and state policy.

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