A COMPREHENSIVE EVALUATION INDICATOR SYSTEM OF SCP IN THE IRON AND STEEL INDUSTRY: A FIELD STUDY IN BAOSTEEL

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Key words: Comprehensive Evaluation Indicator System; SCP; Analytic Hierarchy Process; Multilayer Linear Assessment; Baosteel

			
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Abstract: *The comprehensive evaluation on Sustainable Consumption and Production (SCP) in China's iron and steel industry plays a very important role in the sustainable development of national economy. With the Baosteel Group Corporation (Baosteel) in China, this paper constructs a Comprehensive Evaluation Indicator System (CEIS) for SCP in the steel manufacturing enterprises based on Material Flow Analysis (MFA) and Environmental Cost Accounting. It is unified with physical and value information from the total resource flow process in Baosteel. And this paper carries out a comprehensive analysis and evaluation on SCP's development situation in Baosteel by choosing the model of Analytic Hierarchy Process (AHP) and Multilayer Linear Assessment (MLA). It can provide the basic principles and methods of SCP's evaluation for iron and steel enterprises, and also available for related industries with high pollution and high energy.*

1. INTRODUCTION

As a unique versatile material, steel is used in many fields. There are thousands of different types of steels involving in supporting housing, food supply, transport and energy delivery solutions. In China, iron and steel industry has developed rapidly in the past three decades. In 2011, China produced about 6.8 Mt of crude steel, which rose by 8.8% compared with the previous year. However, as one of the key industries, the iron and steel industry is proved to be high-energy-consumption, high-emission and heavy pollution. For an enterprise, it is vital to evaluate scientifically the status and trends of SCP in business and environmental management systems.

The earliest concept of SCP is proposed by "Agenda 21" of United Nations Conference on Environment and Development in 1992. It believed that the continued deterioration is the major reason of the unsustainable pattern of consumption and production, particularly in industrialized countries. And SCP is the mechanism for achieving sustainable development, thus reducing our environmental impacts and maintaining or improving economic outputs and standards of living. Enterprises and consumers can also save money by using resources such as water, energy and raw materials more efficiently [1].In 2002, a "project framework of sustainable consumption and production for decades" is proposed by the World Summit on Sustainable Development, and aims to promote the regional and national levels for SCP. Currently, more and more governments, enterprises, community groups and consumers begin to promote the SCP; UNEP and other international environmental organizations have launched a series of demonstration pilot and education of SCP; many countries carry out the SCP through legislation and tax measures. Some scholars have already discussed the indicators of SCP, and also proposed the indicators of the framework and methodology. According to the objective of evaluation, then can be divided into three categories[2-6]: the macro–level (international/ country-based, etc.), the regional–level (province/ county-based, etc.), and the micro–level (enterprise- based, etc.), which covers regions, industries and specific industry, etc. And several methods are applied to perform such evaluations, mainly those using the following procedures [7-11]: principal component analysis, projection pursuit model, fuzzy comprehensive evaluation analysis, gray clustering analysis, data envelopment analysis, etc. Based on the research achievements, we have developed the several methods [12-18]: life cycle analysis, energy analysis, the ecological footprint, material flow analysis, resource efficiency and eco efficiency, etc. In spite of many research achievements in the development of the analysis and the evaluation of the SCP, there are also limitations in the past research achievements:(1)The microscopic evaluation is much less developed than the macroscopic evaluation; (2)Indicators primarily rely on physical information, and do not include value information;(3)The relation between indicator system and SCP is fuzzy. Therefore, we must make the optimal choice to improve the efficiencies of the comprehensive evaluation indicators system of SCP in the Iron and Steel Industry.

As we know, a reasonable CEIS is vital to enterprise's environmental management. It is not only the way to evaluate the improvement of programs, but also the basis for decision-making and technical support of SCP. In the process of new industrialization, the iron and steel industry is not only a basic and pillar industry, but also an excellent entry point of SCP's practical application. For this reason, a reasonable CEIS of SCP in the Iron and Steel Industry will contribute to solving the problems of resource and environmental constraints, as well as utilization of water and energy. Especially, As China's largest steel enterprise, Baosteel is also a miniature of China's steel industry and its case study stands for all the iron and steel industry in China to some degree. Through the comprehensive evaluation of SCP in Baosteel, it will change the iron and steel industry into green, environment-friendly and resource-saving industry, thus providing the basic principles and methods for related industry.

2. THE ANALYSIS ON PROBLEMS OF THE IRON AND STEEL INDUSTRY IN CHINA

Iron and Steel industry is an industrial sector that provides raw material in all respects. As the basic foundation of achieving industrialization and modernization, it is named material industry or basic industry. Because of the good physical properties, mechanic and processing performance, the iron and steel has become the indispensable material of agriculture, consumer goods industry, and transportation industry etc. Its level of development is directly related to the development of each department in national economy and the improvement of living standards. Since 1978, Iron and Steel industry has been developed rapidly in the past three decades in China. The iron and steel industry output reached about 6.8 Mt in 2011, which is rose by 8.8% compared with the previous year.

In this study, we investigated 51 iron and steel factories. Through expert consultation, questionnaire analysis and field monitoring, the problem statements of iron and steel industry were briefly presented as follows:

(1)The shortages of resources and energy in China are more and more serious, and the imports dependence of iron ore is more than 60%. In addition, the domestic related resources (oil, gas, coal, etc) are becoming increasingly tight supply, and prices are rising.

(2)For lacking of advanced technologies, the consumption level of resource and energy are quiet high in China's iron and steel industry, but the average water consumption per ton steel in China's iron and steel enterprises is 2 times higher than the advanced level in abroad. The overall energy consumption per ton steel is two times as high as that of U.S., 1.5 times higher than that of Japan, and the C02 emissions per ton steel in China are 1.7 times as much as Japan. All these indices are much higher than those in developed countries.

(3)In China, Iron and steel industry is the most important materials industry of pollution source which can produce such wastage as dust, soot, sulfur dioxide. The iron and steel industry makes over 20% contributions to the total amount of dust discharge in the entire industry. The other pollutant emissions (soot, sulfur dioxide, sewage, sludge) were also arranged in the front position in various industrial sectors, and it results in the most serious environmental pollution. It is urgent to develop SCP's technologies for resource/energy saving and environmental protection.

(4)In addition, one of the most important characteristics of iron and steel industry in China is that industrial concentration is very low, and most of them are medium and small-scale, which is defined as those enterprises with annual output of 500,000 tons or less. Currently, there are as many as 74 key steel enterprises in China with 18 enterprises located in capital city which caused great pressure on the urban environment, and also restricted their own development.

3. CASE STYDY: COMPREHENSIVE EVALUATION OF SCP IN BAOSTEEL

3.1 Environmental performance and environmental cost accounting in Baosteel

3.1.1 The basic status of Baosteel

Baosteel Group Corporation (BGC) is the most competitive steel complex in China at present. In 2010, with the total employees of 106,914 people, Baosteel registered sales revenue of 410.8 billion dollar and got a total profit of 35.9 billion dollar. Baosteel has been enrolled in Global 500 for 7 years consecutively and ranked 276th with 4450 million tons in its production. Therefore, it ranked the top 3 in the global steel companies.

Baosteel underlines environmental protection; implements clean production, develop circular economy and pursue sustainable development. It is the first enterprise to pass ISO-14001 environmental certification in Chinese metallurgical sector and also the first to get the title of "National environment- friendly enterprise" in Chinese metallurgical sector and Shanghai Municipality.

3.1.2 The improvements for SCP in Baosteel based on technical process

It is a long process for the technical process of Baosteel. After sintering and palletizing the raw material of ironstone, it uses the Blast Furnace to produce hot metal. Then by pretreatment of hot metal, through converter steelmaking and External refining, it become the qualified components molten steel. At last, casting the molten steel, so we can make it into different shapes of ingot blank and roll it to the production (Fig. 1).

As showed in figure 1, it covers the material flow and energy flow based on the mode of SCP in Baosteel.

In terms of material flow, Baosteel is a long process of steel production (blast furnace/ converter) similar with other world-class steel mills. In this production flow, iron is first melted from ore, and then refined into steel. Besides iron ore resource, the scrap steel which recycled from waste treatment plant (recycling of waste materials) is also an important source of raw materials. Recently, Baosteel attaches great importance to the energy usage and recycling efficiently in the whole process of steel production for the strategy of SCP.

 In the process of sintering, Baosteel adopted the three sintering desulphurization units, which are designed on their own, and it processes 4,000 tons of SO2 annually. It shows that the units have reliable performance, and the desulphurization effect is obvious;

 In the process of coking, the CDQ unit is used widely in all of the mills, and it is very significant for energy saving and economic benefits. Baosteel have used the" negative energy steel-making" for years. Its comprehensive energy consumption per ton of steel entered into the advanced ranks in the world. With 97.6% of the recycling rate of its industrial water and zero diffuse gas, waste heat recovery has accounted for more than 10% of the total energy consumption;

 "Secondary resource"(or "by product", commonly referred to as "waste")in the process of steel production covers blast furnace slag, steel slag, slag, fly ash, and industrial waste etc. The solid secondary resources have the characteristics of variety and complex composition. In addition to back of the production system, their majority need for treatment and utilization;

 Baosteel develops new technologies of rotating drum steel slag, water slage into powder, fly ash recycling technology etc. It also establishes industry chain system characterized with "resources-production-product-consumption-waste recycles" for the SCP, and solid waste comprehensive utilization rate in Baosteel has reached more than 98%.

Based on the concept of CP, it is considered that the actual production process, the situation of resources, energy consumption and emissions in this industry chain formed the SCP pattern with resource sharing, products exchanging in Baosteel.

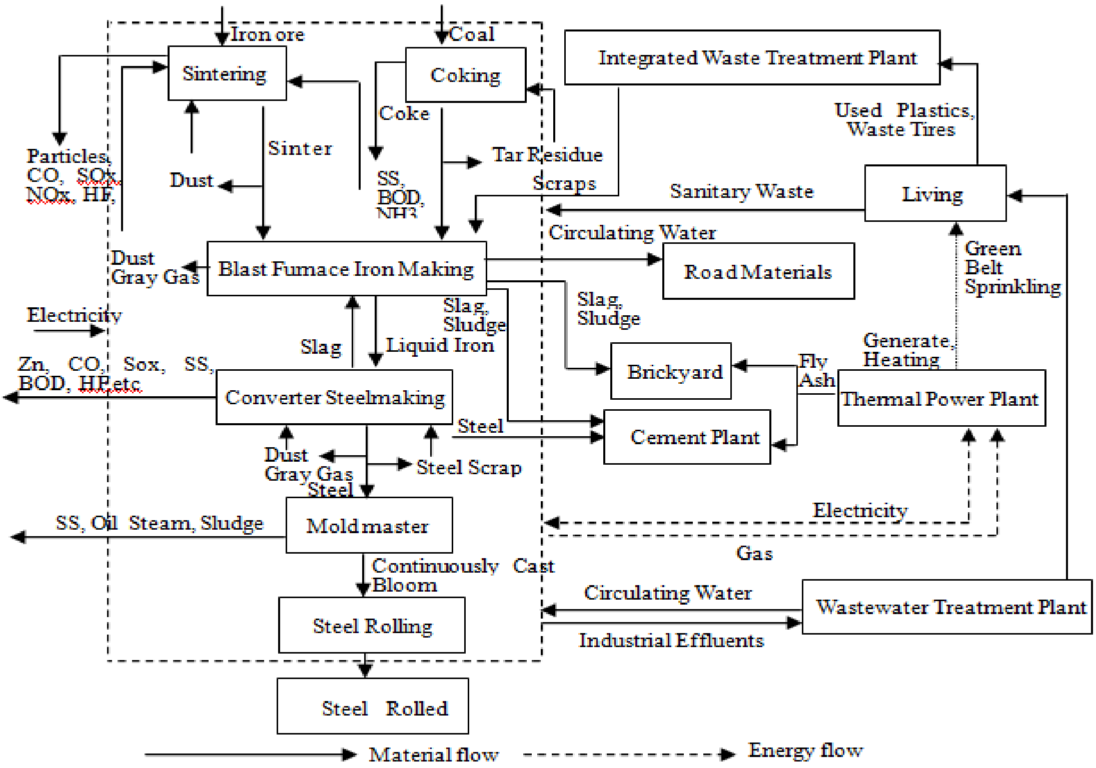

Fig. 1. The production process of Baosteel based on SCP

In terms of energy flow, the main industry products chain of Baosteel is: iron ore fines-scrap steel-coking coal-water-liquid iron (Blast Furnace)-Steel (converter)-steel products, and integrated with this main industry chain of steel production, Baosteel has taken for SCP a series of measures such as followings:

□Industry chain of waste-electricity;

□Industry chain of domestic sewage-sewage treatment plant-raw water system;

□Industry chain of blast furnace slag-cement industry;

□Industry chain of steel scoria-building materials;

□Industry chain of fly ash-cement plant;

□Industry chain of dust and sludge which containing iron-cement plant-sinter.

3.1.3 Environmental cost accounting in Baosteel based on the material flow analysis

The essence of SCP for Baosteel is that resources are used in the most efficient way in production process with the improvement of economic performance and environmental performances at the same time. Therefore, it must set a CEIS with the unity of physical and value information for comprehensive assessment of SCP in Baosteel.

Material flow analysis (MFA) is a method of analyzing the flow of materials in a well-defined system, and is used to calculate indicators, to develop strategies for improving the material flow systems and to produce a better understanding of the flow of materials through an industry and its connected ecosystems. The managers can improve environmental performances by MFA, and it also grasp the whole profile of material flow in their enterprises, but the major disadvantage of MFA is that the value information cannot be provided to the managers [12-18].

The purpose of environmental accounting is to provide the value information of environmental activities for their enterprises [19-20]. Therefore, it is necessary to combine environmental accounting with MFA by carrying out value calculation on material quantity. The environmental cost accounting model, which originated from environmental accounting, can provide detailed value information on material flow in enterprises, which is helpful for the comprehensive assessment of SCP in Baosteel.

The main source of value information lies in the calculation of the resource cost, which can be considered in two parts [21-22]:

(1)Resource effective cost and resource loss cost based on the bargain prices in the market system;

(2)The external environmental damage cost of waste based on the evaluated value outside the market system.

The value of iron element will change from time to time along with the movement of raw materials in Baosteel (Figure 2).

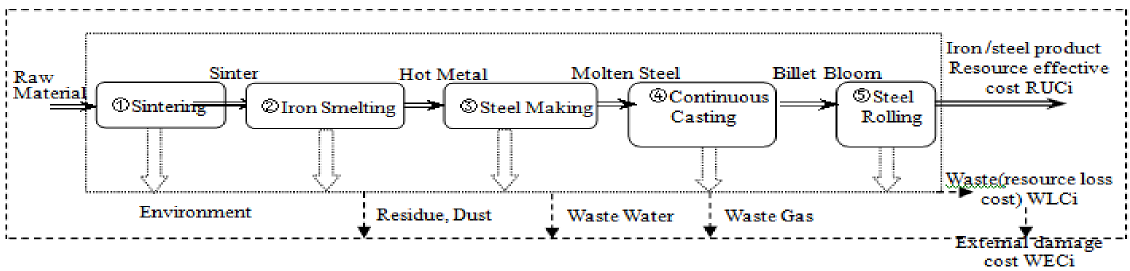

Fig. 2. Principle of material flow and cost type in Baosteel

In order to calculate the corresponding cost, we first divide all the production processes into different physical centers according to the characteristics of resource flow in Baosteel, and then calculate resource effective cost and resource cost committed to product (or semi-manufactured product) separately in each physical center by cost allocation standards (the assignment principle of material costs, labor costs, depreciation costs, in cost accounting). Simultaneously, overhead expenses are also allocated by this standard. For the external environmental damage cost of waste, we compute according to the weights or volumes of iron elements. The computation equation is shown as follows:

$$RUC_i = \frac{MC_i + EC_i + SC_i + OC_i}{QP_i + QW_i} \times QP_i \tag{1}$$

$$WLC_i = \frac{MC_i + EC_i + SC_i + OC_i}{QP_i + QW_i} \times QW_i \tag{2}$$

$$WEC_i = \sum_{i=1, j=1}^{m, n} WEI_{ij} \times UEC_{ij} \tag{3}$$

MC_i is the raw material input cost in i physic center; EC_i the energy input cost in i physic center; SC_i the labor cost in i physic center; OC_i the manufacturing expense in i physic center; QP_i the element weight of qualified products in i physic center; QW_i the element weight of waste in i physic center; WEI_{ij} the waste j in i physic center; and UEC_{ij} the unit environmental damage coefficient of waste j in i physic center.

Formulas (1) ~ (2) are similar to cost distribution in cost accounting. The difficulty with Formula (3) lies in the determination of the environmental damages co-efficiencies because of the uncertainties of the environmental impairments and the absence of their trading markets. Along with the development of environmental science and engineering, environmental economy, the technique of economic assessment of environmental damage is being applied gradually to the environmental management systems of enterprises. For example, A new environmental impact assessment method developed in Japan, known as LIME (Life-cycle Impact assessment Method based on Endpoint modeling), is able to assess human health and biodiversity impacts (LIME calls this "amount of damage"). Thus, we are able to compute the external environmental damage cost of waste by the LIME model, and facilitate a comprehensive evaluation indicator for Baosteel.

3.2 The Construction of CEIS for SCP in Baosteel

3.2.1 The Basic Principle and Screening Procedure of CEIS

Based on the mechanism of MFA and technical characteristics of production process in Baosteel, this paper identifies the quantities of raw material inputs, resource consumption in production processing, and product outputs respectively, and then determines the corresponding cost information for material flow in different production process (input, consumption and circulation, output) according to environmental cost accounting model[23-27]. Then it can further construct CEIS for Baosteel subject to SCP. The “input” indicator mainly focuses on resource productivity and resource consumption of unit products. It reflects the economic nature of resources and the public wealth produced by unit resource consumption. The “consumption and circulation” indicator emphasizes the yield ratio of the added value and the ratio of internal recycling or re-use. It also indicates that the re-use principle can be quantified by calculating the relative proportions of the added value to the output value as well as the ratios of resource re-use in an enterprise. The “output” indicator mainly attaches importance to eco-efficiency and to the comprehensive utilization of waste. The waste utilization is directly connected to the pollution which is converted into new resources.

Following the conceptual framework of CEIS(Fig.3), this paper constructs the evaluation indicator system based on the principle of SCP by adopting a hierarchical structure model. The goal layer expresses the overall ability for the development of SCP in Baosteel. In other words, it shows the overall conditions and trends in an enterprise’s sustainable development. The criteria layer differentiates and refines the goal layer according to

the factors influencing the goal layer. It can be divided into the “input”, “consumption and circulation” and “output” sectors in the overall production process of Baosteel. The indicator layer measures the quantity performance, intensity performance and speed performance of Baosteel by using different indicator groups which are observable, measurable and comparable. Thus, it reflects the comprehensive status and trends of the evolution of SCP in Baosteel, including resource reduction, resource recycling and reuse, emission detoxification, etc.

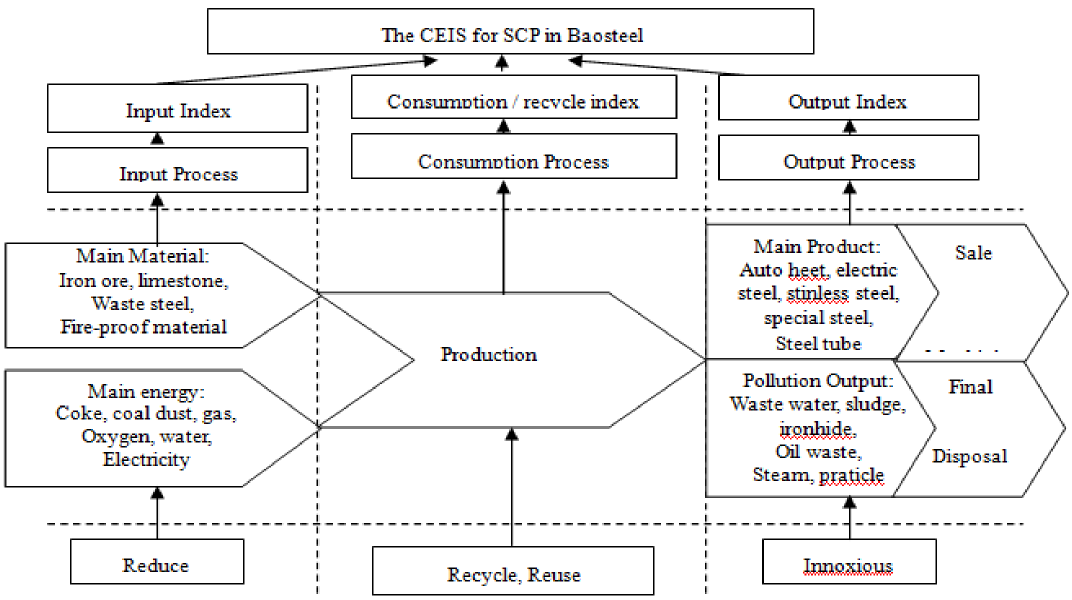

Fig.3. Conceptual Framework of CEIS for SCP in Baosteel

The indicator layer contains many primary indicators, and needs further refining (Figure 4).

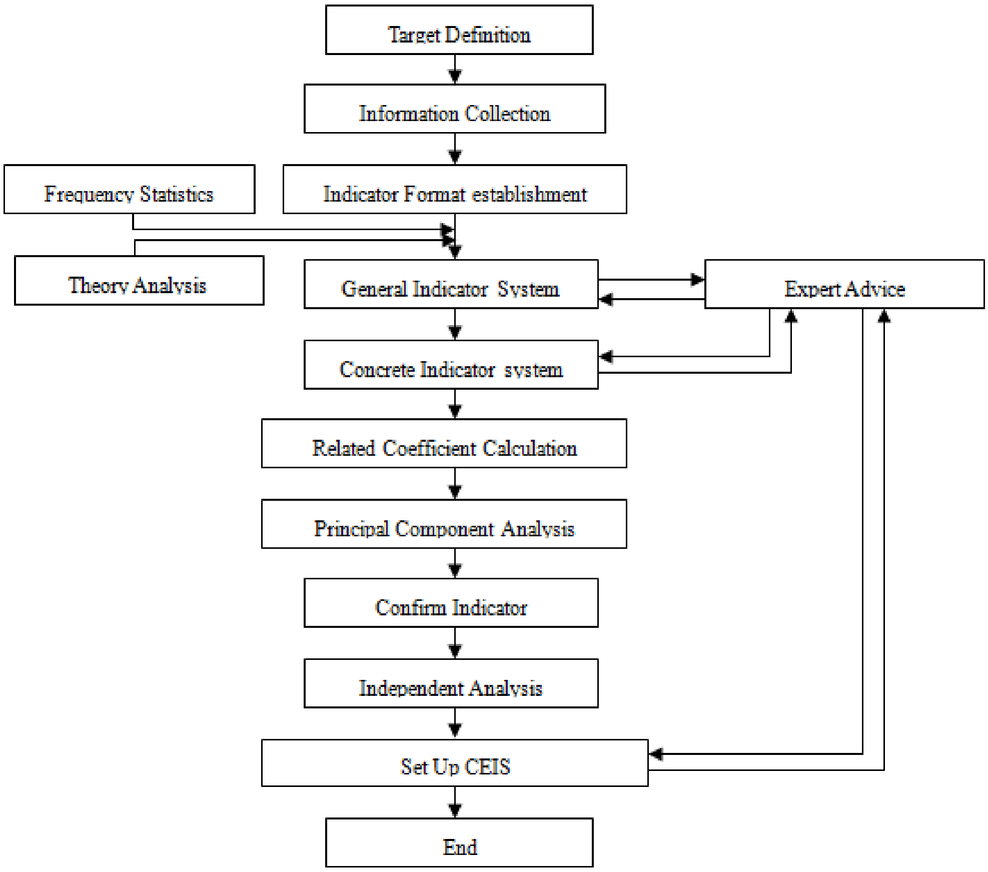

Fig. 4. The Screening Procedure of CEIS

3.2.2 The Indicator Processing

(1) *Appraisal standards.* It is the determination of the ideal indicator, namely the maximum (positive or benefit) or the minimum (negative or cost) of each indicator. At present, the ideal standard mainly covers the normal standards of international, national or industry, optimum standards in related enterprises and ideal standards in theory, etc, so it should be designed according to the requirements of the sustainable development of Baosteel.

(2) *Weight Determination.* There are two ways to determine the indicator weight: an objective synthetic approach and a subjective synthetic approach, each of which has its own advantages. Because the latter is limited by the characteristics of material flow based on the production process in flow manufacturing enterprise, an analytic hierarchy process (AHP) unified with qualitative analysis and quantitative analysis, and is suitable for determining the indicator weight of an appraisal objective. The AHP is characterized by:

• Having the advantage of digitization and systematization of individual thinking, and the ability to reveal intrinsic problem factors in limited data or information;

• Having a "tree" characteristic which not only provides a structure for resource flow, but also increases its flexibility in application;

• Along with accumulated information, being able to improve the objectivity of the indicator weight by combining with Delphi or other objective analysis methods.

(3) Indicator Standardization. Indicator standardization includes the quantification of a qualitative indicator and the standardization of a quantitative indicator (dimensionless). The researchers often use the following methods in practice:

• Linear standardization, which includes threshold value means, exponential means, standardized means(the Z-score means), proportion means and so on;

• Broken line standardization, such as convex broken line means, concave broken line means and three broken line means;

• Curve line means, including half normal distribution, half rise (convex, concave) distribution, half rise range distribution etc.

• Due to the diversity and complexity of indicators in flow manufacturing enterprises, there have been no defined "good" and "bad" quantitative limits to many of these indicators. They exhibit considerable fuzziness and, therefore, fuzzy quantification methods would be more suitable in practice.

3.2.3 The CEIS of SCP in Baosteel

Based on the basic principle of technical process and environmental cost accounting in Baosteel, this paper can calculates the resource loss cost and external environmental damage cost, which are advantageous in establishing the indicator system. After the determination of the indicator forms, the selection of the primary indicator and any amendments to the indicator system, it determines its hierarchical structure (goal layer, criterion layer and indicator layer). Through the collection of data and information from its iron and steel production, it determines the 78 primary indicators using mathematical statistics (e.g. frequency statistics, theory analysis and expert consultation etc.). It then rejects 22 of the indicators which are neither feasible nor accurate, and also eliminates a further 20 indicators after principal component analysis and independent analysis, finally leaving 36 indicators. The evaluation indicator system is shown in Table 1.

Table 1 The CEIS for SCP in Baosteel

Goal layer (first-level indicator)	Criterion layer (second-level indicator)	Indicator layer (third-level indicator)
The CEIS for SCP in Baosteel (H)	resource input and consumption index A	ratio of resource comprehensive yield A1
		main resource consumption of unit product (iron ore) A2
		energy consumption of unit value output A3
		new water consumption of unit value output A4
		comprehensive cost of unit product A5
		raw material input cost of unit net profit A6
		energy input cost of unit net profit A7
		main raw material input of unit net profit A8
		main energy input of unit net profit A9
		water resource consumption of unit net profit A10
		sintering of small pellet(qualitative) A11
		high-efficiency continuous casting (qualitative) A12
	resource flow and recycling index B	added value of unit value output B1
		ratio of industrial water recycling B2
		ratio of interior energy utilization (coal gas, waste heat, etc) B3
		ratio of internal solid wastes resource utilization (tailings, waste residue, smelting slag) B4
		ratio of interior dust and sludge containing iron utilization B5
		comprehensive utilization output value of unit production B6
		comprehensive cost loss of unit value output B7
		ratio of resource cost loss and environmental damage cost loss B8
		ratio of raw material cost loss B9
		ratio of energy cost loss B10
		ratio of system cost loss B11
		comprehensive utilization (consumption) of social waste (qualitative) B12
	resource output and management index C	comprehensive ratio of rolled steel into production C1
		“three-wastes” discharge of unit product C2
		disposal cost of unite waste C3
		waste disposal cost of unit net profit C4
		waste water discharge of unit net profit C5
		gas emissions discharge of unit net profit C6
		solid waste discharge of unit net profit C7
		external environmental damage cost of unite value output C8
		certification of environmental management system (qualitative) C9
		cleaner production auditing(qualitative) C10
		comprehensive control of total waste(qualitative) C11
		harmful levels of “three-wastes”(qualitative) C12

*A11,A12,B12,C9,C10,C11,C12 are qualitative indicator.

1st - resource input and consumption index:

(1)A1-total yield [market price*(finished products + semi-finished products + other products)] resulting from all resource inputs and consumption (e.g. Auto steel, electric steel, stainless steel, special steel, steel tube, etc.) in the production system.

(2)A2- unit consumption of main resource (iron ore).

(3)A3-total energy input per year / total value output per year.

(4)A4-new water consumption per year / total value output per year.

(5)A5-comprehensive cost of unit product including total material cost, energy cost and system cost, etc.

(6)A6-raw material input costs per year/ unit net profit per year.

(7)A7-energy input cost per year/ unit net profit per year.

(8)A8-main raw material input per year/ unit net profit per year.

(9)A9-main energy input per year/ unit net profit per year.

(10)A10- water resource consumption per year / unit net profit per year.

(11)A11- sintering small pellet.

(12)A12- casting high-efficiency.

2nd- resource flow and recycling index:

(1)B1-total value added per year / total value output per year.

(2)B2-recycling water consumption of Baosteel per year / total water consumption of Baosteel per year.

(3)B3-quantity of internal energy utilization per year / quantity of total energy utilization and energy loss per year (coal gas, waste heat, etc).

(4)B4-quantity of internal solid waste resource utilization per year / quantity of total solid waste resource utilization and solid waste resource loss per year.

(5)B5-quantity of dust & sludge containing iron utilization per year/quantity of total dust & sludge containing iron utilization and dust & sludge containing iron loss per year.

(6)B6-comprehensive utilization output value per year /production output per year.

(7)B7-comperhensive cost loss per year (i.e. negative product cost) / total value output per year (covers resource cost loss and resource effective cost).

(8)B8-calculates internal resource cost loss by environmental cost accounting and material flow analysis, and obtains the external environmental damage cost based on the LCA assessment tool (e.g. LIME, MAC etc.).

(9)B9-raw material cost loss per year /raw material cost input per year.

(10)B10-energy cost loss per year /energy cost input per year.

(11)B11-system cost loss per year /system cost input per year.

(12)B12-comprehensive utilization (or consumption) of social waste.

3rd- resource output and management index:

(1)C1-comprehensive ratio of rolling steel into production: steel content in the input of iron ore /steel content in the output of qualified steel products.

(2)C2-the discharge of wastewater, gas emission and solid waste per year / steel production per year.

(3)C3-this indicator reflects the pure profit loss, which explains the financial influence of the enterprise resulting from waste disposal.

(4)C4-waste disposal cost per year/unit net profit per year.

(5)C5-waste water discharge per year/unit net profit per year.

(6)C6-waste gas discharge per year/unit net profit per year.

(7)C7-solid waste discharge per year/unit net profit per year.

(8)C8-external environment damage cost which occupies the proportion of the total product value output of Baosteel. The numerator of the indicator (external environment damage cost) is the economic impact assessment value of environmental pollution (air pollution, water pollution, light pollution, noise, solid waste etc.) which is produced in production and operation activities (material supply, production, goods sale, resource recycling, waste discharge, etc.)of Baosteel. It also includes the ecological damage originating from over-consumption of natural resources.

(9)C9-the establishment and certification of environmental management system.

(10)C10-cleaner production auditing

(11)C11-comprehensive control of total waste

(12)C12-harmful levels of "three-wastes"

3.3 The Comprehensive Evaluation Model Based on MLR

3.3.1 Evaluation Method and Process

The development of SCP in Baosteel is a dynamic coordination in production process, that is to say, it can achieve the optimal goals cored with the harmonization between resource consumption, environmental protection and economic performance of enterprise, which should be assessed from development level, development speed and development coordination. Integrated with qualitative and quantitative analyses, the MLA model has three advantages [28-29]:

• It is suitable for the multi-objective appraisals of SCP in flow manufacturing enterprise, such as iron and steel enterprise, aluminum enterprise;

• The evaluation indicator system has the characteristics of multi-level distribution, and this model decomposes a general goal into many sub-goals at multi-levels, thus obtaining more reasonable conclusions;

• This model can analyze the relationship between independent variables and dependent variables accurately, and help the manager track favorable and unfavorable factors in the implementing SCP.

• As shown in Figure 5, it is very clear that the key steps of MLA are first to construct an indicator system that adopts indicator standardization, and second to calculate development index, development coefficient and coordinated coefficient of SCP in Baosteel; and finally to make comprehensive evaluations appropriate to regional level (evaluation rank).

3.3.2 The Principle of MLA

Because the MLA is suitable for the multi-objective appraisals of SCP, and also can analyze the relationship between independent variables and dependent variables accurately, we choose the MLA model. Details of the process are as follows:

(1) Development index of SCP. This includes resource input index, resource consumption and recycling index, resource output index. For sample i :

$$U_{ki} = \sum_{j=1}^{n} w_{ij} \times B(X_{ij})$$

where U_{ki} is the development index for sample i ; $k = 1, 2, 3$ resource input index, resource consumption and recycling index, resource output index for sample i ; $B(X_{ij})$ the actual fuzzy membership value for indicator D_i in sample i ; w_{ij}

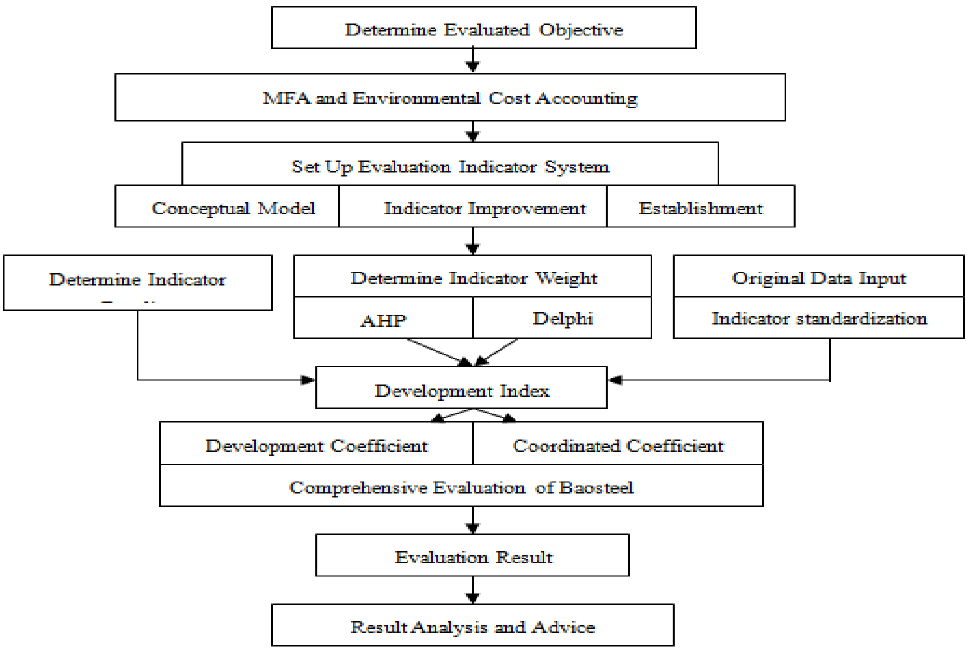

Fig. 5. Evaluation Process of SCP in Baosteel Based on MLA

the indicator weight for D_i in sample i ; and n the indicator number for sample i .

(2) Development coefficient of SCP. This can be reflected in the total status and ability of the SCP in Baosteel. For sample i this is:

$$C_{ki} = \sum_{k=1}^{3} W_k \times U_{ki} \qquad (5)$$

There k is the index number of development coefficient of SCP $(k = 3)$.

(3) Coordinated co-efficiency of SCP. When the numerical values of $U1$, $U2$ and $U3$ are closer to each other, it indicates that the SCP is coordinated between different systems, and its numerical value approaches 1. Otherwise it is not coordinated, its numerical value approaches 0; for sample i this is:

$$H_i = 1 - S_i / F_i \qquad (6)$$

Where Si is standard deviation of these indices for sample i; and Fi is the mean value of these indices for sample i.

(4) Regional level. One of the prime purposes of comprehensive evaluation is to determine the gap between sample indicator and goal indicator groups. Therefore, if development coefficient of SCP for sample i were defined (Table 2), the indicator group with low correlation would be regarded as having weak recycling (0≤C<0.5); the indicator group with obvious correlation would be called basic recycling（0.5≤C<0.8）;the indicator group with high correlation would be categorized as strong recycling（0.8≤C≤1.0）. Similarly, we can coordinate the coefficients (Table 3) as follows. When0.8≤H ≤1.0, these indices for sample i are very close to each other, the indicator in CEIS has entered into advanced phase of coordinated development. When0.5≤H<0.8, these indicators have entered into basic phase of coordinated development. When 0≤H<0.5, these indicators are not coordinated and the enterprise has deviated from the direction of SCP's development.

Table 2 Coefficient of SCP Development Categories

rank	I	II	III
development coefficient for SCP C	$0 \le C < 0.5$	$0.5 \le C < 0.8$	$0.8 \le r \le 1.0$
Status	weak recycling	basic recycling	strong recycling

Table 3 SCP Coordinated Coefficient Categories

rank	I	II	III
coordinated coefficient for SCP H	$0 \le H < 0.5$	$0.5 \le H < 0.8$	$0.8 \le H \le 1.0$
Status	weak coordinated development	basic coordinated development	Strong coordinated development

(5) Comprehensive evaluation (Table 4). It is a two-dimensional appraisal model with development coefficient (vertical, development continuity) and coordinated coefficient (horizontal, development coordination) for SCP.

3.4 Data Collection and Result Analysis

Initially, this paper presents the primary data and information from 2006-2010 (we only list the calculation process in 2006), which comes from corporate social responsibility report, monthly report for production, financial report, internal management report, and the survey report of environmental pollution, etc. It then obtains the relative weight of each indicator according to the degree of relative importance based on the AHP and Delphi, that is 5 experts and 5 managers who come from Baosteel mark the relative importance of every indicator. It is shown in Table 4.

Table 4 Categorization of Characteristics of SCP's Development

development characteristics of SCP	development coefficient of SCP C	coordinated coefficient of SCP H
strong recycling and strong coordinated development (A)	0.8≤C≤1.0	0.8≤H≤1.0
strong recycling and basic coordinated development (B)		0.5≤H<0.8
strong recycling and weak coordinated development (C)		0≤H<0.5
basic recycling and coordinated development (D)	0.5≤C<0.8	0.8≤H≤1.0
basic recycling and basic coordinated development (E)		0.5≤H<0.8
basic recycling and weak coordinated development (F)		0≤H<0.5
weak recycling and strong coordinated development (G)	0≤C<0.5	0.8≤H≤1.0
weak recycling and basic coordinated development (H)		0.5≤H<0.8
week recycling and weak coordinated development (I)		0≤H<0.5

Table 5 Calculation of Relative Weight of Second-level Indicators

H	A	B	C	bj	Wj	AW		
A	1.00	0.75	1.00	0.9086	0.3000	0.90	λmax=	3
B	1.33	1.00	1.33	1.2114	0.4000	1.20	CI=	0
C	1.00	0.75	1.00	0.9086	0.3000	0.90	RI=	0.5148
total				3.0286	1.00		CR=	0

After obtaining the relative weight of indicators in the second- and third-levels, the evaluation system determines the ideal numerical value for each indicator in Baosteel. This is according to the criterion of a national environmental protection, the standards for cleaner production in iron steel industry in China and the standards of iron steel enterprises overseas(i.e. Arcelor Mittal, Nippon Steel Corp., Pohang Iron & Steel Co.,Ltd., etc.). The integrated development index for different levels is shown as follows after index standardization:

Table 6 Comprehensive Index of SCP Development in Baosteel

Indicator layer (third-level indicator)	actual value of indicator	Ideal value of indicator	appraisal of third-level indicator	weight of third-level indicator	appraisal of second-level indicator	weight of second-level indicator	appraisal of first-level indicator
A1	1.8010	1.9210	0.9375	0.0911			
A2	1.2800	1.2300	0.9609	0.0812			
A3	1.1900	1.1500	0.9664	0.0823			
A4	3.6500	3.2300	0.8849	0.0783			
A5	3037	2899	0.9546	0.0923			
A6	2.7296	2.6208	0.9601	0.0732	0.8995	0.3000	
A7	1.0572	1.3051	0.8101	0.0832			
A8	1.7782	1.5228	0.8564	0.0884			
A9	1.1798	0.8919	0.7560	0.0765			
A10	10.0292	8.9582	0.8932	0.0934			
A11	5.0000	5.0000	1.0000	0.0823			
A12	4.0000	5.0000	0.8000	0.0778			
B1	0.4680	0.5000	0.9360	0.0864			
B2	0.9760	0.9440	0.9672	0.0907			
B3	31.0000	31.0000	1.0000	0.0828			
B4	0.9832	0.9850	0.9982	0.0743			
B5	0.0602	0.0640	0.9406	0.0831			
B6	0.5148	0.4800	0.9324	0.0814	0.9170	0.4000	0.9158
B7	0.1300	0.1000	0.7692	0.0798			
B8	12.4000	13.0080	0.9533	0.0852			
B9	0.0938	0.0900	0.9595	0.0912			
B10	0.0274	0.0232	0.8467	0.0851			
B11	0.0281	0.0249	0.8861	0.0835			
B12	4.0000	5.0000	0.8000	0.0765			
C1	1.0505	1.1000	0.9550	0.0881			
C2	2.1800	2.0000	0.9174	0.0856			
C3	160.9000	154.2000	0.9584	0.0813			
C4	0.2788	0.2564	0.9197	0.0789			
C5	4.6468	3.4291	0.7379	0.0734			
C6	5.5328	5.0291	0.9090	0.0824	0.9305	0.3000	
C7	9.9460	9.2790	0.9329	0.0855			
C8	0.0100	0.0000	0.9800	0.0868			
C9	5.0000	5.0000	1.0000	0.0878			
C10	5.0000	5.0000	1.0000	0.0900			
C11	5.0000	5.0000	1.0000	0.0873			
C12	4.0000	5.0000	0.8000	0.0729			

As shown in Table 6, the comprehensive index for SCP is 0.9158 (H) in 2006, and Baosteel developed well compared with the ideal numerical value of indicator. The resource input index (A) returned a value of 0.8995, the resource consumption and recycling index (B) a value of 0.9170, and the resource output index (C) a value of 0.9305. The resource consumption and recycling returned the best value which was closer to the ideal numerical value.

The resource input index and the resource output index also returned good values. From these indices, we know that there is still potential for improvement in resource input, products output and waste processing in the future. The coordinated coefficient and recycling coefficient are shown in Table 7:

Table 7 The Coordinated and Recycling Coefficients of SCP

A	B	C	Standard deviation Si	Coordinated coefficient Hi
0.8995	0.9170	0.9305	0.0284	0.9583
A	B	C	Mean value Fi	Recycling coefficient Ci
0.8995	0.9170	0.9305	0.9157	0.9158

It was discovered that resource input, resource consumption and recycling, and resource output indices are coordinated with each other in Table 5 (the coordinated index of 0.9643 is close to 1), and the relationships of indicator system are more balanced. Using a similar approach, we calculated the results of the coordinated and recycling coefficients for SCP in Baosteel from 2006 to 2010. The result of this comprehensive evaluation is displayed in Figure 6 for the 5 years:

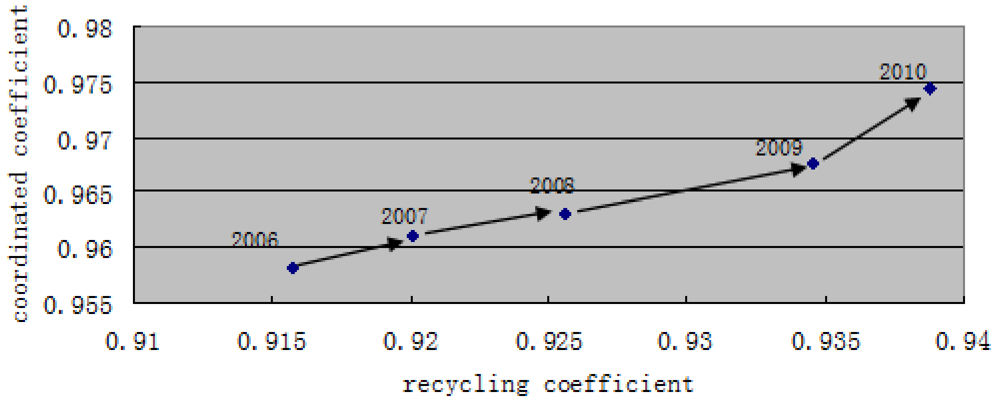

Fig. 6. Trends to Comprehensive Evaluation of SCP in Baosteel

It is very clear that the effects of SCP's development are quite remarkable during 2006-2010 as a result of the improvements in the environmental management measures and application of technology in Baosteel. The two coefficients were increasing stability during five years and the growth improvements were a little positive during 2008-2010. Looking at the trends of the recycling coefficient of the SCP, the indicator of the evaluation system is approaching the ideal goal year by year. Similarly, from the results of coordinated coefficients, the resource input index, resource consumption, recycling index and resource output index values are progressively closing with each other, which indicates that Baosteel has entered into a phase of coordinated development. It is important to maintain the healthy status of coordinated development between various systems for SCP in Baosteel.

Before the implementation of the CEIS, Baosteel made evaluations based on the draft of the evaluation indicator for CP in iron and steel industry (published in 2006). While the draft only focuses on technical indicators in production process, and there was no inclusion of value information, so it is not helpful to managers' decision-making for SCP in Baosteel. The CEIS emphasizes the balancing role of value and physical information, and it is more comprehensive and advanced than evaluation indicator in draft. Though environmental management indicators in environmental accounting stress the win-win outcomes of environmental benefits and economic profits, all the indicators are more fragmented and do not form a unified system. The CEIS not only focuses on value and physical information of evaluation indictor, but also emphasizes its integrity and comprehensiveness. It is a more valuable tool for enterprise managers.

In enterprise's environmental management systems, the CEIS can be executed regularly every month, quarter or year. While it can evaluate the status of the SCP for different individual enterprises at a moment in time, it also can assess the trends of the SCP of an individual enterprise over different periods. In addition, the basic principles of the CEIS can be further applied to processes, plants or groups. If there are new resource/energy-saving technologies or measures for CP to be implemented in an enterprise, it can evaluate the comprehensive effects on the SCP of a typical enterprise resulting from the application of the new technology or measure, that is to say, it can make a comparative analysis for the SCP before and after the implementation of CP.

4. CONCLUSIONS

As a new production and consumption patterns, SCP is an important strategic path for an enterprise's sustainable development. It is necessary to build a reasonable evaluation indicator system which is matched with the SCP in an enterprise. Noting the characteristics of manufacturing processes in Baosteel, and based on MFA and environmental cost accounting, this paper constructs a CEIS unified with physical and value information from the total resource flow process (input, consumption and recycling, output and disposal)by AHP&MLA in Baosteel. Compared with existing evaluation indicator systems for cleaner production and evaluation indicators in environmental accounting, it is more comprehensive and provides more information for SCP's decision-making in business and environmental management system.

The case study shows that the effects of SCP's development are quite remarkable as a result of the improvements of environmental management and cleaner production in Baosteel. Furthermore, the results provide reliable theoretical and technological support for evaluating the development of SCP in the iron and steel industries of China. However, Further studies to assess effects of the SCP in other Chinese iron and steel enterprises are needed, especially in related industries with high consumption and high emission, including mining and metallurgy, chemical, building materials, petrochemical, papermaking, brewing, food processing, etc.

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