A Comprehensive Evaluation of the Development of Recycling Economy in Flow Manufacturing Enterprises: A Case Study of an Electrolytic Aluminum Enterprise in China

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Abstract

As a new developing economy in the 21st century, there have always been concerns about the scientific evaluation of a recycling economy. However, existing methods for the evaluation of a recycling economy focus on physical information, neglect value information; pay much attention to indicator systems, overlook specific case studies; think highly of complicated mathematical models, and make light of practical issues. Furthermore, environmental management indicators, which are widely available in environmental accounting, are not fully utilized and the application is relatively immature. Therefore, the indicator system needs to further complement the enterprise's environmental management system, especially for enterprises with high pollution and high energy usage.

Based on the principle of material flow analysis and resource value accounting models in enterprise(s), through defining and tracking the value information of resource inputs, consumption, output and disposal in the production process, this paper builds a new evaluation index system of a recycling economy from the total process of resource flow (input, consumption and recycling, output). Compared with traditional evaluation index systems, this indicator system better displays the basic characteristics of value information in an enterprise, not only the physical information of resource flow, but also the 3R principle of recycling economy directly. The paper takes an electrolytic aluminum enterprise as a typical example. It analyzes the development situation and development trends of a recycling economy of a typical enterprise using the model of an Analytic Hierarchy Process (AHP) and Multilayer Linear Assessment (MLA) with the characteristics of a development index. It will also analyze the development and coordination co-efficiencies of the recycling economy. This model will be more rigorous in theory as well as simpler in practice compared with other methods. Thus, it can provide a more effective method for the comprehensive evaluation of a recycling economy in flow manufacturing enterprises and related industries.

[Key words] Recycling Economy; Comprehensive Evaluation and Analysis; Indicator System; Electrolytic Aluminum Enterprise; AHP &MLA

1. Introduction

As an innovative economy model in the 21st century, recycling economy has developed rapidly in recent years. Its analysis and appraisal have been key topics in recycling economy research. Internationally there have been many research achievements in the development of the analysis and the evaluation of a recycling economy. Depending on the different appraisal objectives, we can divide this research into three categories: the macro-level (international-, country-based, etc.), the regional-level (province-, county-based, etc.), and the micro-level (enterprise-based, etc.) (Adriaan A. 1993; Spangenberg, J. etc. 1998; Hashimoto, S. etc, 2004; Tai-yang Zhong. etc. 2006)[1). We can also categorize the research according to mathematical methods adopted for the indicator system, namely: principal component analysis, fuzzy comprehensive evaluation analysis, gray clustering analysis, and neural network analysis (EUROSTAT. 2001; Scasny, M. etc. 2003; Hai-feng Huang. 2005; Jiu-Ling Zhang, etc. 2007). Some researchers developed comprehensive evaluation index systems for the recycling economy based on different theories or tools, such as energy analysis, the ecological footprint, material flow analysis(MFA), and eco-efficiency, etc. (Azat, C. etc. 1996; Klaus Hubacek, etc. 2003; Raymond Ct., etc. 2006). However, there are limitations to the research achievements to date, including the following:

1. Little has been achieved at the micro-level (e.g. enterprise etc.);
2. Evaluation indicators are scattered and limited in number, there has been no correlation between indicators, and some evaluation models are over complicated making them difficult to understand, especially for accountants;
3. Evaluation indicator systems rely primarily on physical information (energy analysis, MFA, etc), and do not include value information.

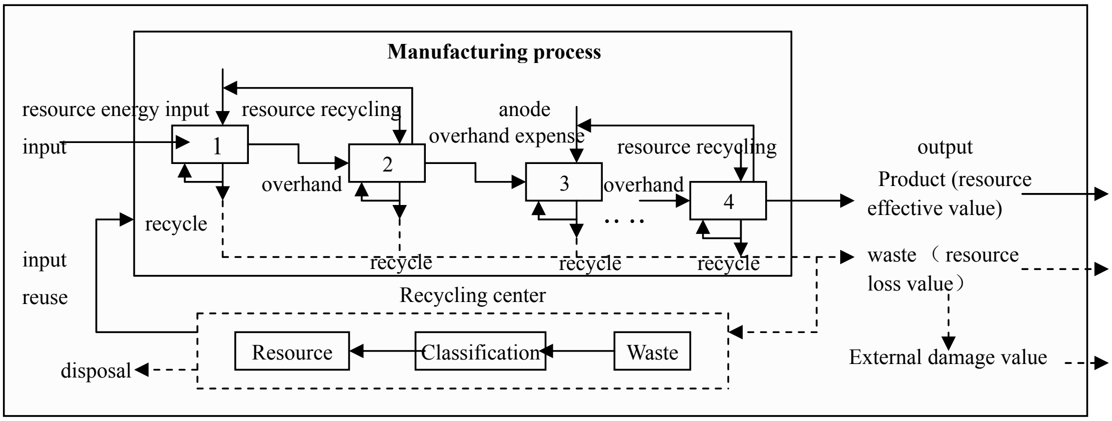
In summary, it is difficult to make the right environmental management decisions for managers based on the available evaluation indicator systems.

For an enterprise, the scientific evaluation of the status and trends of a recycling economy is vital in business and environmental management systems. For example, the well known “PDCA” Cycle, namely “Plan-Do-Check-Act”, is a key management tool of the ISO14000 Environmental Management System. The “PDCA” Cycle-based management is applied worldwide in enterprises’ environmental management activities. However, if there were no scientific checks for the results of a plan’s execution with a reasonable evaluation and analysis system, decision-makers would not take the right action to improve the process, which might affect the total “PDCA” Cycle. Related indicators in environmental accounting can also evaluate environmental and financial performance, such as the EII (Eco-Improvement Index) and the Eco Index, etc. (Toshiyuki Matsuo.2009), and some of them have been applied in companies. For example, the Ricoh Group has adopted several environmental management indicators, such as the REP (Ratio of Eco Profit), REE (Ratio of Eco Effect), RPS (Ratio of Profit to Social Cost), and so on (Ricoh Group. 2008). These indicators are fragmented, and do not provide a unified approach. It is difficult to evaluate comprehensively the status of a recycling economy, especially for internal relationships between resource consumption, economic benefits and environmental protection in the total process of the resource flow in an enterprise.

Therefore, it is very necessary to establish a suitable scientific and comprehensive evaluation indicator system for a recycling economy in an enterprise’s environmental management system. To establish such a comprehensive evaluation indicator system would require some key tools in the research fields of recycling economy (e.g. MFA) which can calculate the corresponding resource value, and acquire adequate physical and value information indicators. The evaluation indicator system should also emphasize the relationship between resource consumption, economic benefits and environmental indicator performance. In addition, it should focus on key indicators, rather than include all indicators.

2. Material Flow Analysis and Resource Value Calculation in Flow Manufacturing Enterprises under Recycling Economy

Material flow analysis (MFA) is a method of analyzing the flow of materials in a well-defined system, and is used to produce a better understanding of the flow of materials through an industry and its connected ecosystems; to calculate indicators, and to develop strategies for improving the material flow systems. MFA is the basis of material flow management. It can be divided into the following three types (Bringezu, S. etc. 2001a; Hammer, M. etc. 2003; Rotten Bernd. etc. 2004):



1,2,3,4-the physic center in production processes.
Source: Zhifang Zhou, The Construction and Application of Resource Flow Accounting in Flow Manufacturing Enterprise under Recycling Economy: Experience from Chinalco. Yokohama Business Review, forthcoming with some modifications.

Figure 1 Principle of Material Flow and Value Flow of Resource in Flow Manufacturing Enterprises under Recycling Economy

(1)National or Regional scale: In this type of study the material exchanges between an economy and the natural environment need to be analyzed. Indicators are calculated in order to assess the levels of resource intensity of the system;

(2)Corporate material flow analysis: The goal of material flow analysis within a company is to optimize the production processes in such a way that materials and energy are used in the most efficient manner (e.g. by recycling and reduction of waste, resource sharing, etc.);

(3)In the life cycle of a product: This is another term for the life cycle inventory step in life cycle assessment.

The essence of a recycling economy for an enterprise is that resources are used in the most efficient way. It tries to obtain the biggest comprehensive benefit (resource consumption, economic benefits and environmental protection) by consuming the least resources as far as possible. The key issue is resource allocation and management in an enterprise under a recycling economy[2)]. Enterprises can improve their operations costs and environmental performances as a result of implementing a material flow analysis. The managers can also grasp the whole profile of resource flow in their enterprises, and be clear about the physical and value information from their resource inputs, consumption and outputs.

The major disadvantage of MFA is that the value information cannot be provided to the managers. The purpose of environmental accounting is to provide the value information of environmental activities for their enterprises. Therefore, it is necessary to combine environmental accounting (e.g. environmental cost accounting tools, MFCA etc.) and MFA by carrying out value calculations on material quantities (for example, resource input costs, disposal costs, resource value added benefits, etc.). The resource value accounting model, which originated from environmental accounting, can provide detailed value information on resource flow and management in enterprises, which is helpful for the comprehensive assessment and analysis of a recycling economy in enterprises.

The main source of value information lies in the calculation of the resource value, which is a large-scale concept in an economy-environment system. It not only includes resource prices and costs, but the environmental harm value of the resource on the ecological system because of resource consumption and waste discharge. Therefore, the resource value can be considered in two parts[3)]:

⑴Resource effective values (including positive product costs) and resource value losses (including negative product cost) based on the bargain prices in the market system;

⑵The external environmental impairment value of waste based on the evaluated value outside the market system.

In flow manufacturing enterprises, the materials generally include different elements (e.g. Fe—Iron in iron and steel plant, Al—aluminum and Pb—lead in non-ferrous metal enterprises), and the value of these elements, which will change along with the movement of raw materials in the enterprise (Figure 1).

In order to calculate the corresponding resource value, we first divide all the production processes into different physical centers according to the characteristics of the resource flow in the flow manufacturing enterprise. We then calculate the resource effective value and resource value committed to the product (or semi-manufactured product) separately in each physical center by the 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 impairment value of resources or wastes, we compute according to the standard weights or volumes of the elements. The computation equation is shown as follows:

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

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

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

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 UEV_{ij} the unit environmental damage coefficient of waste j in i physic center.

Formulas ⑴–⑵ are similar to cost distribution in 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 ecology, environment accounting and environmental economy, the technique of economic assessment of environmental damage is being applied gradually in the environmental management systems of enterprises (Itsuda Norihiro. etc. 2005).

Through comparative analysis, a more typical method is the Life-cycle Impact assessment Method based on Endpoint modeling (LIME)[4]. This computes the characteristic coefficient and harm coefficient according to important lists, and categorizes different environment harm materials to obtain a single monetized index of the comprehensive environmental harm coefficients of unit wastes. Thus, we are able to compute the external environmental harm value of resources or wastes for an electrolytic aluminum enterprise by the LIME model, and facilitate a comprehensive evaluation indicator for typical enterprises.

3. The Comprehensive Evaluation Indicator System of Recycling Economy Development in Flow Manufacturing Enterprises

Generally, after initial resources are acquired by an enterprise (Figure 1), they flow along the production processes until finally; the materials are turned into new resources, namely finished products and wastes (partial refluxes, re-use and other partial disposals). Part of a resource may circulate in the interior processes of the enterprise or return to its

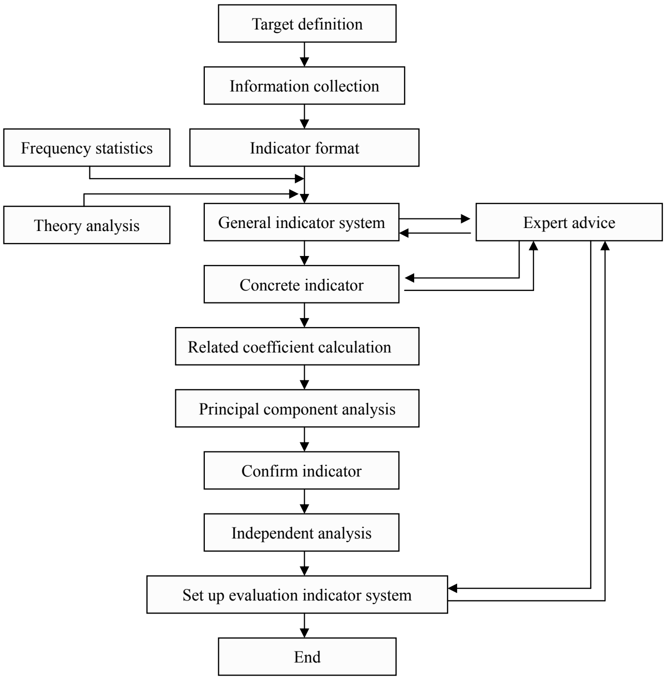


Figure 2 Procedure of Construction of Comprehensive Evaluation Indicator System

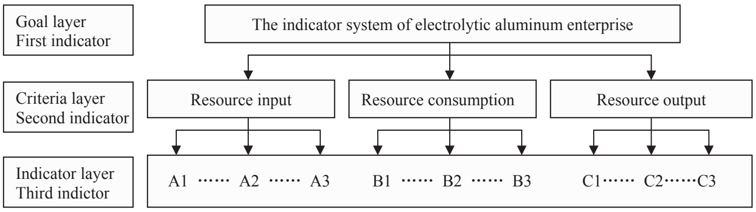


Figure 3 AHP Model of Evaluation Indicator System in Flow Manufacturing Enterprise

original state. The resource value flows in the enterprise along with the associated physical forms.

Therefore, based on the mechanism of material flow analysis and environmental accounting, this paper identifies raw material inputs, resource consumption in production processing, and product outputs for an enterprise, and then determines the corresponding value information of resource flow for the resource "entrance", "circulation" and "export". The "entrance" indicator mainly focuses on resource productivity (output value/resource inputs) and resource consumption of unit products. It reflects the economic nature of resources and the public wealth produced by unit resource consumption. It also identifies the relative degree of reduction of resource inputs as a function of the scale with which an enterprise adopts the reduction principles of a recycling economy. The "circulation" indicator emphasizes the yield ratio of the added value (value added/output value) and the ratio of internal recycling or re-use. It also establishes that the re-use principle can be quantified by calculating the relative proportions of the added value to the output value as well as from the ratios of resource re-use in an enterprise. The "export" indicator mainly attaches importance to eco-efficiency (pollutant discharge/value added) and to the comprehensive utilization of waste. The waste utilization is directly connected to the pollution which is converted into new resources, and embodies the recycling principles.

Following the principles of evaluation indicator systems[5)], this paper constructs a comprehensive indicator system based on the principles of a recycling economy by adopting a hierarchical structure model (Figure 3). The goal layer expresses the overall ability for recycling economy development in an enterprise. 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 mainly into the "entrance", "circulation" and "export" sectors in the overall production process of an enterprise. The indicator layer measures the quantity performance, intensity performance and speed performance of an enterprise, using different indicator groups which are observable, measurable and comparable. Thus, it reflects the comprehensive status and trends of the evolution of a recycling economy in an enterprise, including resource reduction, resource recycling and reuse, emission detoxification, etc. The indicator layer contains many primary indicators, and needs further refining (Figure 2).

4. The Comprehensive Evaluation of Recycling Economy Development in Flow Manufacturing Enterprises

4.1 Appraisal Standards, Weight Determination and Indicator Standardization

(1)The appraisal standard 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, ideal standards in theory, etc. Because of the peculiarities of production processes in flow manufacturing enterprises, the appraisal standard should be designed according to the requirements of the enterprise's sustainable development.

(2)The indicator weight reflects the relative proportion of the indicator in an appraisal objective. 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 (Adriaanse A., 1993; Dumanski J., Pirei C., 2001). Although the former reflect the real purpose of an appraisal, but is easily influenced by subjective factors; the latter avoid manual intervention, but cannot reflect the relative importance of the goal and is supported by large quantities of primary data. Because the objective synthetic approach is limited by the characteristics of resource flow in a flow manufacturing enterprise, an analytic hierarchy process, (AHP, Figure 4) unified with qualitative analysis and quantitative analysis, 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 includes the quantification of a qualitative indicator and the standardization of a quantitative indicator (dimensionless). As a result of the complexity of indicator quantification, there are still no perfect ways to quantify a qualitative indicator at present, although researchers often use the following methods in practice (Ehrenfeld T., Crertler N., 1997; Rotten Vera Susanne. etc., 2004):

- 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;

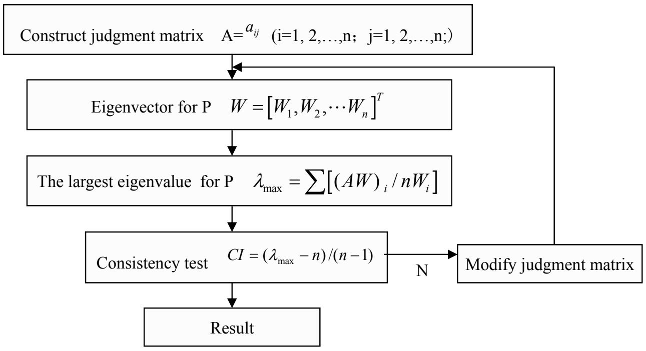


Figure 4 Analytic Hierarchy Process (AHP)

- 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. The applied steps are:

- Determine the bound of “good” indicators or “bad” indicators, namely the maximum and minimum for each indicator;
- Determine the type of fuzzy membership function for each indicator;

For example, a (sales) positive indicator would adopt the fuzzy membership function of a half rise trapezoid:

$$B(X_i) = \frac{X_i - X_{min}}{X_{max} - X_{min}} = \begin{cases} 1 & X_i \ge X_{max} \\ \dfrac{X_i - X_{min}}{X_{max} - X_{min}} & X_{min} < X_i < X_{max} \\ 0 & X_i \le X_{max} \end{cases} \tag{4}$$

where $B(X_i)$ is the actual fuzzy membership value for the indicator D_i; X_i the numerical value for the indicator D_i; X_{max} the maximum of the indicator D_i; and X_{min} the minimum of the indicator D_i.

Similarly, a (pollutant discharge) negative indicator would adopt the fuzzy membership function of half fall trapezoid:

$$B(X_i) = \frac{X_{max} - X_i}{X_{max} - X_{min}} = \begin{cases} 1 & X_i \le X_{min} \\ \dfrac{X_{max} - X_i}{X_{max} - X_{min}} & X_{min} < X_i < X_{max} \\ 0 & X_i \ge X_{max} \end{cases} \tag{5}$$

As a final example, a moderate indicator, would adopt the fuzzy membership function of half rise-fall trapezoid:

$$B(X_i) = \begin{cases} \dfrac{2(X_i - X_{min})}{X_{max} - X_{min}} & X_{min} < X_i < X_{i0} \\ \dfrac{2(X_{max} - X_i)}{X_{max} - X_{min}} & X_{min} < X_i < X_{max} \\ 0 & X_i \le X_{min} \ or \ X_i \ge X_{max} \end{cases} \tag{6}$$

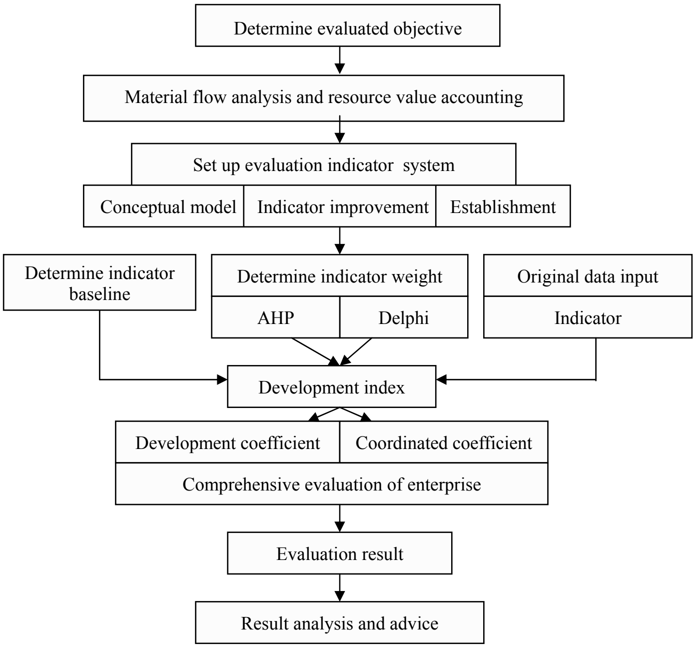


Figure 5 Comprehensive Evaluation Process of Recycling Economy Development in Flow Manufacturing Enterprise Based on Multiple Linear Assessment

where X_{i0} is the optimal numerical value for the indicator D_i.

- Fuzzy transformation. The fuzzy membership value can be obtained by taking the actual numerical values for indicators X_i into their corresponding fuzzy membership function, which aims to eliminate the influence of dimensions (attributes to [0, 1]).

4.2 Comprehensive Evaluation Model Based on Multi-layer Linear Assessment

In recent years, researchers used many comprehensive evaluation models to positively appraise the development of recycling economy objectives (e.g. national, regional, enterprise-based. etc.) as follows (DW Patterson, 1998; Egmont Petersen, M. 2002; Binder Clandia R., etc. 2004; Yuhong Wang. etc., 2007):

- The fuzzy judgment model—this is based on the fuzziness of the impact factor under a recycling economy;
- The gray multi-layer appraisals model—this stems from the “gray” characteristics (incomplete information) of an evaluation system for a certain objective under a recycling economy;
- Multi-dimensional statistical analysis model—this mainly includes factor analysis and principal components analysis;
- The data envelope analysis model[6)]—in recent years, this method has developed rapidly in China, but it is difficult to apply at the micro-level because of the complex mathematical derivation.

In addition, researchers have carried out comprehensive evaluation for some regional recycling economy models by means of artificial neural networks (ANP)[7)], but this is an immature model in practice.

The development of the recycling economy of enterprises is a harmonious process for various reasons, namely, enterprises can achieve their optimal goals from the development level, the development speed and the development coordination. Integrated with qualitative and quantitative analyses, the multi-layer linear assessment model has three advantages (Charnes. W., 1987; Mahesh Pal, etc., 2003; Ke-ping Leng, etc., 2005):

- It is suitable for the multi-objective appraisals of a recycling economy;
- 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 it can obtain 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 evolving recycling economy.

As shown in Figure 5, it is very clear that the key steps of multi-layer linear assessment are first, to construct an indicator system that adopts indicator standardization; second, to calculate the development index, development coefficient and coordinated coefficient of the recycling economy in the enterprise; and finally, to make comprehensive evaluations appropriate to the regional level (evaluation rank).

Details of the process follow:

(1)Development index of a recycling economy. This includes the resource input index, the resource recycling index and the resource output index. For sample i (e.g. an enterprise):

$$U_{ki} = \sum_{j=1}^{n} w_{ij} \times B(X_{ij}) \tag{7}$$

where U_{ki} is the development index for sample i; k=1, 2, 3, which present the resource input index, recycling index and output index for sample i; $B(X_{ij})$ is the actual fuzzy membership value for indicator D_j in sample i ; W_{ij} is the indicator weight for D_j in sample i ; and n is the indicator number for sample i.

(2)Development coefficient of recycling economy. This can be reflected in the total status and ability of the recycling economy in an enterprise. For sample $i$this is:

$$C_{ki} = \sum_{k=1}^{3} W_k \times \mathrm{U}_{ki} \tag{8}$$

where k is the index number of development coefficient of recycling economy (k=3).

(3)Coordinated co-efficiency of recycling economy. When the numerical values of U_1, U_2 and U_3 are closer to each other, it indicates that the recycling economy is coordinated between different systems, and its numerical value approaches 1. Otherwise, it is not coordinated, and its numerical value approaches 0; for sample i this is:

$$C_{ki} = \sum_{k=1}^{3} W_k \times \mathrm{U}_{ki} \tag{9}$$

where S_i is the standard deviation of the resource input, recycling and output index for sample i ; and $\bar{F}_i$ is the mean value of the resource input, recycling and output index for sample i.

(4)Regional level. One of the prime purposes of comprehensive evaluation is to determine the gap between the sample indicator and goal indicator groups. Therefore, if the development coefficient of recycling economy for sample i were defined (Table 1), the indicator group with low correlation would be regarded as having weak recycling ($0 \leq C < 0.5$), the indicator group with obvious correlation would be called basic recycling ($0.5 \leq C < 0.8$), the indicator group with high correlation would be categorized as strong recycling ($0.8 \leq C < 1.0$). Similarly, we can coordinate the coefficients (Table 2) as follows. When $0.8 \leq H < 1.0$, the resource input, recycling and output index for sample i are very close to each other, and these indicators have entered into the advanced phase of coordinated development. When $0.5 \leq H < 0.8$, these

Table 1 Coefficient of Recycling Economy Development Categories

rank	I	II	III
development coefficient of recycling economy C	$0 \leq C < 0.5$	$0.5 \leq C < 0.8$	$0.8 \leq C < 1.0$
Status	weak recycling	basic recycling	strong recycling

Table 2 Recycling Economy Coordinated Coefficient Categories

rank	I	II	III
coordinated coefficient of recycling economy H	$0 \leq H < 0.5$	$0.5 \leq H < 0.8$	$0.8 \leq H < 1.0$
Status	weak coordinated development	basic coordinated development	Strong coordinated development

Table 3 Categorization of Characteristics of Recycling Economy Development

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

indicators have entered into the basic phase of coordinated development. When $0 \leq H < 0.5$, these indicators are not coordinated, the enterprise has deviated from the direction of recycling economy development.

(5)Comprehensive evaluation (Table 3). This paper uses a two-dimensional appraisal space (Figure 6) with the development coefficient (vertical, development continuity) and the coordinated coefficient (horizontal, development coordination) of the recycling economy.

According to the position of sample i in Figure 6, the manager can precisely determine the status of the recycling economy in the enterprise, and make appropriate decisions for the enterprise' s environmental management. In addition, the manager can observe the trends of the recycling economy in the enterprise through time series analysis.

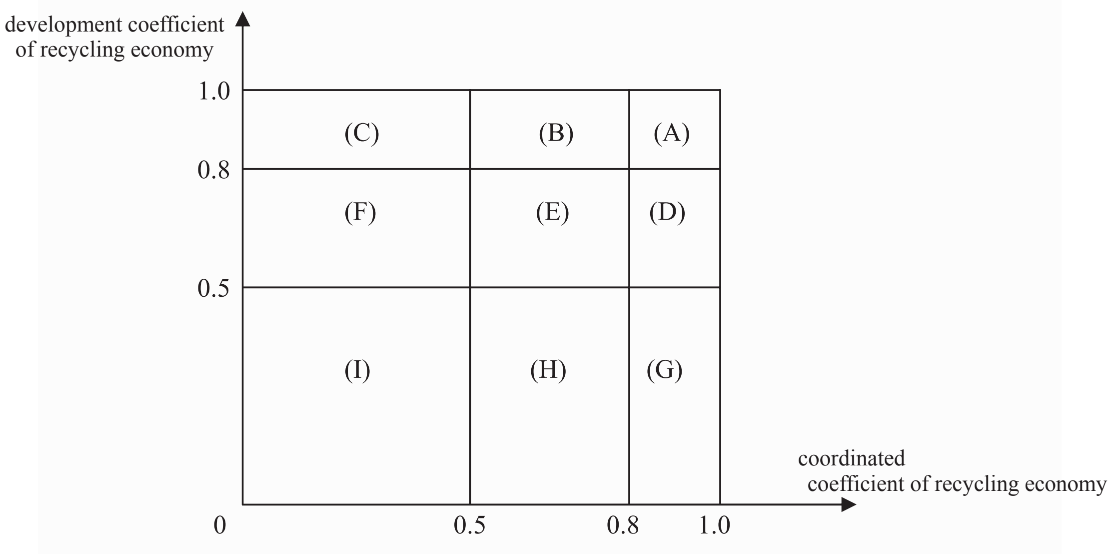


Figure 6　Categorization of Characteristics under Recycling Economy Development

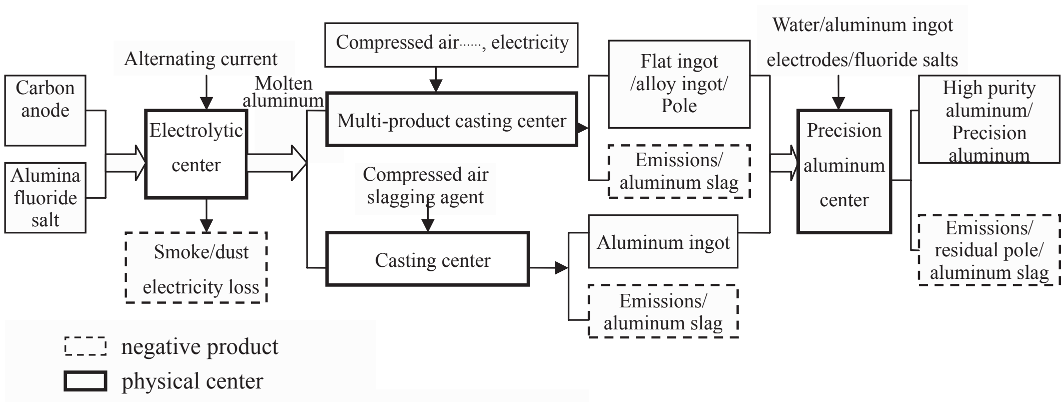


Figure 7　Path of Resource Flow in Electrolytic Aluminum Enterprise

5. Case Study - An Electrolytic Aluminum Enterprise in China

5.1 Construction of a Comprehensive Evaluation Indicator System in an Electrolytic Aluminum Enterprise

This paper takes a large-scale electrolytic aluminum enterprise in China as an example[8)]. Initially, the primary mineral resource inputs include alumina, cryolite, and anodes. Then, through a series of different processes (e.g. the electrolysis process in the electric tank) and coordinated movements (the aluminum fluid produced at the negative pole is re-melted in a stove after vacuum ladling), it produces a range of aluminum products and by-products (such as the casting of aluminum ingots or aluminum products from casting machines). It also produces castoffs and emissions (CO_2, CO and fluoride), all of which result in serious environmental pollution. According to the characteristics of the technical process, it creates an interior physical center (Figure 7), collects data of resource flows in different physical centers,

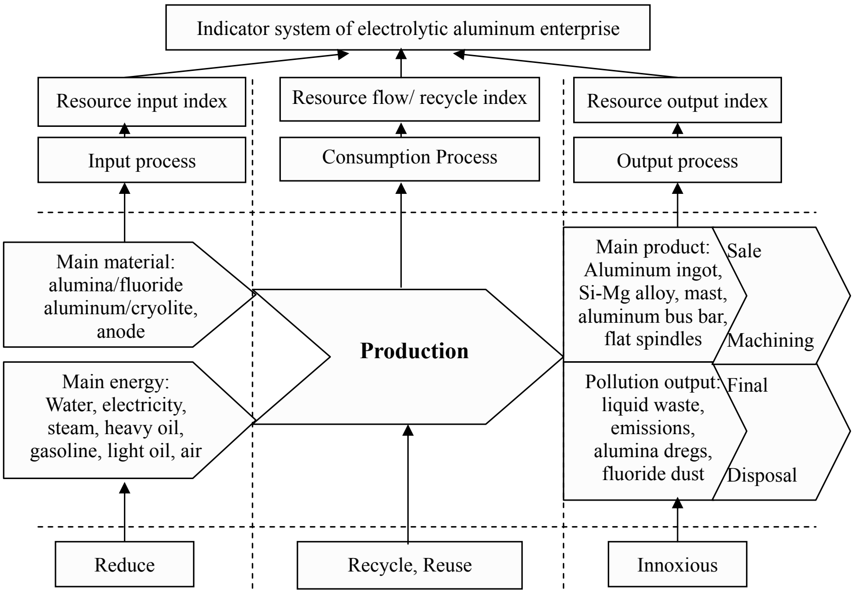


Figure 8 Conceptual Framework of an Evaluation Indicator System in an Electrolytic Aluminum Enterprise Based on the BOM (Bill of Material) of MFA

and then calculates the resources' effective values, resource value losses and external environmental impairment values, separately (Equations 1-3).

Based on the computation process of the indicator system, the resource flow path and the conceptual framework for evaluating the indicator system (Figure 8), this paper further calculates the resource value information by environmental accounting and MFA (e.g. positive product cost, negative product cost, waste disposal cost, etc.), which is 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 electrolytic aluminum production, it determines the 75 primary indicators using mathematical statistics (e.g. frequency statistics, theory analysis and expert consultation etc.)[9]. It then rejects 28 of the indicators which are neither feasible nor accurate, and also eliminates a further 23 indicators after principal component analysis and independent analysis, finally leaving 24 indicators. The evaluation indicator system is shown in Table 4.

1st - resource input index:

(1)A1—total yield [market price*(finished products + semi-finished products + other products)] resulting from all resource inputs and consumption (e.g. alumina, aluminum fluoride, cryolite, calcium fluoride, anode, petroleum, etc.) in the production system.

(2)A2—main resource consumption (covers alumina, carbon anode and fluoride salt) of unit aluminum ingots.

(3)A3—comprehensive energy consumption[10] (e.g. coal, petroleum and natural gas etc.) of unit aluminum ingots.

(4)A4—electrical energy consumption of the electrolytic aluminum production system per year/the production output of aluminum ingot per year.

Table 4 Evaluation Indicator System of Recycling Economy Development in Electrolytic Aluminum Enterprise

Goal layer (first-level indicator)	Criterion layer (second-level indicator)	Indicator layer (third-level indicator)
Indicator system of electrolytic aluminum enterprise under recycling economy(H)	resource input index A	ratio of resource comprehensive yield A1
		main resource consumption of unit productA2
		energy consumption of unit product A3
		electrical energy consumption of unit product A4
		alumina inputs of unit value output A5
		energy consumption of unit value output A6
		new water consumption of unit value output A7
		comprehensive cost of unit product A8
	resource flow and recycle index B	added value of unit value output B1
		ratio of resource value loss B2
		ratio of resource value loss and environmental impairment value loss B3
		current efficiency B4
		ratio of internal resource utilization B5
		ratio of interior aluminum utilization B6
		ratio of interior energy utilization B7
		ratio of industrial water reuse B8
	resource output index C	ratio of "three-wastes" comprehensive utilization C1
		disposal cost of unite waste C2
		dry purification efficiency C3
		"three-wastes" discharge of unit product C4
		waste water discharge of unit value added C5
		gas emissions discharge of unit value added C6
		solid waste discharge of unit value added C7
		external impairment value of unite value output C8

(5)A5—total alumina input per year/total value of the output per year (market price * finished product).

(6)A6—total energy input per year/total value output per year.

(7)A7—new water consumption per year/total value output per year.

(8)A8—comprehensive cost including total material cost, energy cost and system cost, etc.

2nd - resource flow and recycle index:

(1)B1[11)]—total value added per year/total value output per year.

(2)B2—resource value losses per year (i.e. negative product cost)/total resource value per year (covers resource value losses and resource effective value).

(3)B3—calculates internal resource value loss by environmental accounting and material flow analysis methods, and obtains the external environmental impairment value based on the LCA assessment tool (e.g. LIME, MAC, etc.).

(4)B4[12)]—actual aluminum output/theoretical aluminum output per year * 100%.

(5)B5—quantity of internal resource utilization per year/quantity of total resource utilization and waste output per year.

(6)B6—quantity of internal aluminum utilization per year/quantity of total aluminum utilization and aluminum loss per year.

(7)B7—calculation similar to that of B6.

(8)B8—interior reuse water consumption of the enterprise per year/total water consumption of the enterprise per year.

3rd - resource output index:

(1)C1—[ratio of waste water utilization + ratio of emissions utilization (e.g. CO_2, SO_2, etc.) + ratio of solid waste utilization (e.g. aluminum dregs, etc.)] /3.

(2)C2—this indicator reflects the pure profit loss, which explains the financial influence of the enterprise resulting from waste disposal.

(3)C3—waste (fluorine and dust) purification quantity per year/total waste (fluorine and dust) production quantity per year.

(4)C4—production of unit aluminum ingots that bring about the discharge of wastewater, gas emissions and solid waste.

(5)C5—waste water discharge produced by a value added unit. Waste water discharge refers to the gross discharges to the natural environment after passing through the recycling and waste treating centers. It is used to appraise the environmental pollution status of the electrolytic aluminum enterprise.

(6)C6—emissions of waste gas produced by a value added unit.

(7)C7—solid waste discharge produced by a value added unit.

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

5.2 Data Collection and Result Analysis

Initially, this paper presents the primary data and information from 2003–2007 (we only list the calculation process in 2007), which comes from the cleaner production report, the financial report, the internal business and management report, the general survey report of environmental pollution, and the resource flow analysis report[13], etc. It then obtains the relative weight of each indicator of this enterprise according to the degree of relative importance based on the Analytic Hierarchy Process and Delphi, namely, 5 experts and 5 managers who come from this electrolytic aluminum enterprise mark the relative importance of every indicator. This is shown in Table 5[14].

After obtaining the relative weight of the indicators in the second- and third-levels, the evaluation system determines the ideal numerical value for each indicator in an electrolytic aluminum enterprise. This is according to the criterion of a national recycling economy, the standard for cleaner production in the aluminum industry in China and the standard of the electrolytic aluminum enterprises overseas(i.e. Alcoa, Alcan, etc.). The integrated development index for the different levels is shown as follows after index standardization.

As shown in Table 6, the comprehensive index for the recycling economy is 0.8738 (H) in 2007, and this enterprise developed well compared with the ideal numerical value of the indicator. The resource input index (A) returned a value of 0.8768, the resource flow and recycle index (B) a value of 0.9080, and the resource output index (C) a value of 0.8252. The resource flow and recycle index 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 indexes, we know that there is still potential for improvement in the resource input, products output and waste processing in the future. The coordinated

Table 5 Calculation of Relative Weight of Second-level Indicators in the Evaluation System

H	A	B	C	bj	Wj	AW		
A	1.00	0.75	1.00	0.9086	0.3000	0.90	λ max=	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=	0.5149
total				3.0285	1.00		CR=	0

Table 6 Comprehensive Index of Recycling Economy Development in an Electrolytic Aluminum Enterprise

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	2.010	1.800	0.90	0.1509			
A2	2113.560	1894	0.92	0.1563			
A3	6252	5200	0.83	0.1063			
A4	14779	14500	0.98	0.1173	0.8768	0.3000	
A5	4.627	3.341	0.72	0.1263			
A6	34.007	33.365	0.98	0.1001			
A7	13.760	10.355	0.75	0.0995			
A8	0.709	0.645	0.91	0.1433			
B1	0.467	0.500	0.93	0.1653			
B2	0.054	0.000	0.80	0.1695			
B3	9.820	10.000	0.98	0.0995			
B4	0.928	0.940	0.99	0.0951	0.9080	0.4000	0.8738
B5	0.941	1.000	0.94	0.1030			
B6	0.952	1.000	0.95	0.1173			
B7	0.701	1.000	0.70	0.1053			
B8	0.950	0.950	1.00	0.1450			
C1	0.899	1.000	0.90	0.1812			
C2	0.000	0.000	1.00	0.1155			
C3	0.943	1.000	0.94	0.1323			
C4	0.648	0.400	0.64	0.1032	0.8252	0.3000	
C5	0.000	0.000	1.00	0.1032			
C6	1.290	0.000	0.21	0.1032			
C7	0.000	0.000	1.00	0.1032			
C8	0.006	0.000	0.81	0.1581			

Table 7 The Coordinated and Recycling Coefficients of Recycle Economy

A	B	C	Standard deviation Si	Coordinated coefficient Hi
0.8768	0.9080	0.8252	0.0418	0.9519
A	B	C	Mean value Fi	Recycling coefficient Ci
0.8768	0.9080	0.8252	0.8700	0.8738

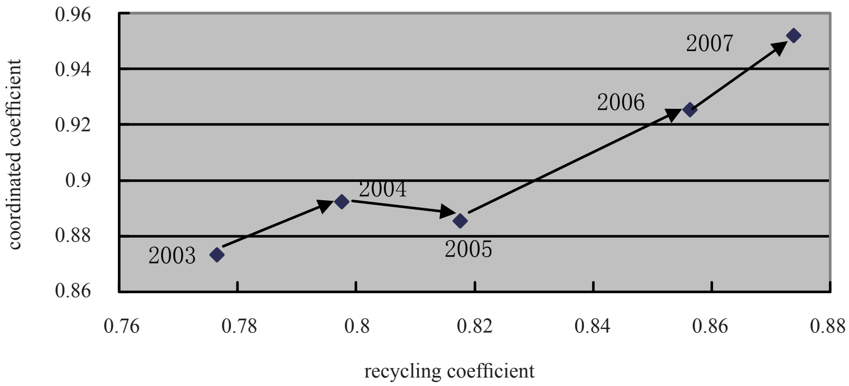


Figure 9 Trends to Comprehensive Evaluation of Recycling Economy Development in Electrolytic Aluminum Enterprise

coefficient and recycling coefficient are shown in Table 7:

It was discovered that the resource input, resource flow and recycle, and resource output indexes are coordinated with each other in Table 7 (the coordinated index of 0.9519 is close to 1), and the relationships of the indicator system are more balanced. Using a similar approach, we calculated the results of the coordinated and recycling coefficients of the recycle economy in the electrolytic aluminum enterprise from 2003 to 2006. The result of this comprehensive evaluation is displayed in Figure 9 for the 5 years.

It is very clear that the effects of recycling economy development are quite remarkable during 2003-2007 as a result of the improvements in the environmental management measures in the electrolytic aluminum enterprise[15). Although two coefficients were fluctuating during 2003-2005, the growth improvements were very positive during 2006-2007. Looking at the trends of the recycling coefficient of the recycling economy, the indicator of the evaluation system is approaching the ideal goal year by year. Similarly, from the results of the coordinated coefficients, the resource input index, resource flow and recycle index and resource output index values are progressively closing in on each other, indicating that this enterprise has entered into a phase of coordinated development. It is important to maintain the healthy status of coordinated development between the various systems to improve further the recycling economy in the electrolytic aluminum enterprise.

Before the implementation of the comprehensive evaluation indicator system, this enterprise made evaluations based on the draft of the evaluation indicator system for cleaner production in the primary aluminum industry (published in 2006). On the basis of the draft, the focus was only on the technical indicators in the production process. There was no inclusion of the value information, so managers decided to improve it through R & D cooperation projects[16).

The comprehensive evaluation indicator system reported in this paper emphasizes the balancing role of value and physical information in the environmental management decision-making and recycling economy. This made it more comprehensive and advanced than the draft indicators. Though environmental management indicators in environmental accounting stress the combination of value and physical information, and pay attention to the win-win outcomes of environmental protection and economic benefits, all the indicators are more fragmented and do not form a unified system. The comprehensive evaluation index system not only focuses on value and physical information, and on the relationships between of resource consumption, economic efficiency and environmental protection, but also emphasizes its integrity and comprehensiveness. It is a more valuable tool for enterprise managers.

In business and environmental management systems, this comprehensive evaluation indicator system can be executed regularly every month, quarter or year. While it can evaluate the status of the recycling economy for different individual enterprises at a moment in time, it also can assess the trends of a recycling economy of an individual enterprise over different periods (short-, medium- and long-term trends). In addition, the basic principles of the evaluation indicator system can be further applied to production lines, production workshops, production plants or corporate groups. Naturally, the specific indicator will be changed depending on the actual data and information of the enterprise, but will typically cover resources inputs and outputs, production technology, production process characteristics, product types, cost accounting and accounting application models, organizational structure and management methods, and so on.

If there are new environmentally-friendly technologies, energy-saving technologies or environmental management measures to be implemented in an enterprise, it can evaluate the comprehensive effects on the recycling economy of a typical enterprise resulting from the application of the new technology or measure. Namely, it can make a comparative analysis for a recycling economy before and after the implementation of the new technology or measure.

6. Conclusions

As a new development pattern, recycling economy is an important strategic path for an enterprise's sustainable development. It is necessary to build a reasonable evaluation indicator system which is matched to the environmental strategic management and evaluation in an enterprise. Noting the characteristics of resource flow in flow manufacturing enterprises, and based on MFA and resource value flow accounting, this paper constructs a comprehensive evaluation indicator system which is unified with physical and value information from the total resource flow process by AHP&MLA in an electrolytic aluminum enterprise. It makes a positive evaluation and an actual test. Compared with existing evaluation indicator systems for cleaner production and evaluation indicators in environmental accounting, it is more comprehensive and provides more information for recycling economy management decision-making. Thus, it provides a scientific tool for evaluating the status of the recycling economy in electrolytic aluminum enterprises, and it is also available for enterprises in related industries, including mining and metallurgy, chemical, building materials, petrochemical, papermaking, brewing, food processing, etc.

Of course, because resource value accounting model is still in its initial stages of development, there have been difficulties over data collection and data availability in practice, but this needs to be constantly improved to facilitate further research.

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References

Hashimoto, S., Moriguchi, Y. 2004. Proposal of six indicators of material cycles for describing society's metabolism: from the viewpoint of material flow analysis. Resources, Conservation and Recycling 40, 185–200.

Spangenberg, J., Bonnoit, O. 1998. Sustainability indicators: A compass on the road towards sustainability. Wuppertal Paper. No. 81, February 1998, Wuppertal.

Tai-yang Zhong, Xian-jin Huang, Chen Wang, 2006. The development evaluation of regional recycling economy: methods, indicators and Empirical Study—A Case Study of Jiangsu Province. Resource Science, (2): 154–161, in Chinese

Loew, E. Moran and D. Holmes. 1995. A Filedbook for the Development of Eco-Industrial Parks. Report for the U.S. Environmental Protection Agency, Oakland, California: Indigo Development International.

A. J. D. Lambert, F. A. Boons. 2003. Eco-industrial parks: stimulating sustainable development in mixed industrial parks. Technovation (22) .

Adriaan A. 1993. Environmental Policy Performance Indicators. Uitgeverij, The Hague: A study on the development of indicators for environmental policy in The Netherlands.

Scasny, M., Kovanda, J., Hak, T. 2003. Material flow accounts, balances and derived indicators the Czech Republic during the 1990s: results and recommendations for methodological improvements. Ecological Economics, 45(1), 41–57.

EUROSTAT. 2001. Economy-wide material flow accounts and derived indicators: A methodological guide. Statistical Office of the European Union, Luxembourg.

Jiu-ling Zhang, Xiao-dong Dong, Zhi-dan Tang, 2007. The statistical analysis and evaluation of circular economy indicators of the mining town based on principal factor analysis. Science and Technology Consulting Herald, (14): 180, in Chinese.

Hai-feng Huang, Hong-hua Zhang, Wen-xiang Cai. 2005. The evaluation of eco-industrial park based on gray clustering method. The Journal of Zhejiang Technology University, (4): 379–402, in Chinese.

Jing-tao Pan, Zhi-hong Wang, 2006. The general indicators for evaluation of recycling economy in mining town based on artificial neural network. Opencast Mining Technology, 2006 (2): 62–64, in Chinese.

Bin Liu, Su-liang Wang, 2005. The construction of index system of circular economy in China based on material flow analysis. China Population, Resource and Environment, (4): 32–36, in Chinese.

Klaus Hubacek, Stefan Giljum. 2003. Applying physical input-output analysis to estimate land appropriation (ecological footprints) of international trade activities. Ecological Economics, (44): 137–151.

Gjalt Huppes, Masanobu Shikawa, 2005. Eco-efficiency and Its Terminology. Journal of Industrial Ecology, 9(4):43–46.

Raymond Ct, Aaron Booth, Bertha Louis, 2006. Eco-efficiency and SMEs in Nova Scotia, Canada. Journal of Cleaner Production, 14(227): 542–550.

Azar, C., Holmberg, J., Lindgren, K. 1996. Socio-ecological indicators for sustainability. Ecol. Econ., (18):89–112.

Toshiyuki Matsuo.2009. Research on environmental financial accounting: The possibilities of conceptual expansion of assets and liabilities in environmental domain, Dissertation Paper (draft). 66–72, in Japanese.

Ricoh Group. 2008. Sustainability Report. http://www.ricoh.com/environment/report/.

Koichi Fujie & Naohiro Goto. Materials Flow Analysis and Modeling to Establish a Zero- Emission Network in Regional Areas, p. 59–68.www.unu.edu/zef/publications_e/fujie_and_goto.pdf.

Rotten Bernd. Vera Susanne, Kost, Thomas, Winkler, Joerg and Bilitewski, Bernd. 2004. Material flow analysis of RDF-production process. Waste Management, Volume 24 Issue 10, 1005–1021.

Bringezu, S., Schütz, H. 2001a. Material use indicators for the European Union,1980–1997. Economy-wide material flow accounts and balances and derived indicators of resource use. EUROSTAT Working Paper. No. 2/2001/B/2. Wuppertal Institute, Wuppertal.

Bringezu, S., Schütz, H. 2001b. Total material resource flows of the United Kingdom, Final report. EPG 1/8/62. Wuppertal Institute, Wuppertal.

Hammer, M., Giljum, S., Bargigli, S., Hinterberger, F., 2003. Material flow analysis on the regional level: questions, problems, solutions. NEDS Working Paper. No. 2, Hamburg.

Itsuba Norihiro, et al., 2005. environmental impact assessment of material flow. Tokyo: Industrial Environmental Management Association. in Japanese.

Dumanski J., Pirei C., 2001. Land quality indicators: research Plan. Agriculture Ecosystems and Environment, (81): 93–102.

Adriaanse A., 1993. Environmental policy Performance indicators, Uitgeverij, The Hague: A study on the development of indicators for environmental policy in the Netherlands.

Rotten Vera Susanne, Thomas, et al., 2004. Material flow analysis of RDF- production process, Waste Management, Volume 24, Issue 10, Pages 1005–1021.

Ehrenfeld J., Crertler N., 1997. The evolution of interdependence at Kalundborg, Journal of Industrial Ecology, 1(1): 67–80.

Binder Claudia R., Hofer, Christoph et al., 2004. Transition towards improved regional wood flows by integrating material flux analysis and agent analysis: The case of Appenzell Ausserrhoden, Switzerland. Ecological Economics, (49): 1–17.

L. I. Smirnov, M. V. Frontas'eva, E. Steinnes, et al., 2004. Multidimensional Statistical Analysis of the Concentration of Heavy Metals and Radionuclides in Moss and Soil in Southern Urals. Atomic Energy, Volume 97, Number 1, 510–515.

Gupta, A. K. , Girko, Vyacheslav L., Girko, V. L., 1996. Multidimensional Statistical Analysis and Theory of Random Matrices: Proceedings of the Sixth Eugene Lukacs Symposium. Walter de Gruyter, 121–143.

Jun-Yen Lee, 2005. Comparing SFA and DEA methods on measuring production efficiency for forest and paper companies, Forest Products Journal, Vol. 55, 7–8.

Ramanathan, R., 2003. An Introduction to Data Envelopment Analysis: A tool for Performance Measurement, Sage Publishing.

Yuhong Wang; Dang, Y., 2007. Model and application of grey comprehensive cluster ex-post evaluation Systems, Man and Cybernetics, IEEE International Conference on Volume, Issue: 3860–3864.

D. W. Patterson,1998. Artificial neural networks: theory and applications. Prentice Hall PTR Upper Saddle River, NJ, USA, 23–49.

Egmont Petersen, M., de Ridder, D., Handels, H., 2002. Image processing with neural networks - a review, Pattern Recognition 35 (10): 2279–2301.

Mahesh Pal, Paul M. Mather, 2003. An assessment of the effectiveness of decision tree methods for land cover classification. Remote Sensing of Environment. 554–565.

Ke-ping Leng, Zhong Huo, 2005. The applied research on performance evaluation model of the Balanced Scorecard strategy with gray correlation analysis. Modern Management Science, 2005 (8): 34–36, in Chinese.

Charnes, W.W. Cooper, E. Rhodes, 1987. Measuring the Efficiency of Decision Making Units. European Journal of Operational Research. (2-6): 429–444.

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Notes

1) Regardless of how it is classified, the most important one is the comprehensive evaluation of a recycling economy in an enterprise, because it is the basic element of a market economy.

2) Resource is defined as the material that can be used or consumed by an enterprise. It includes raw material and energy, but does not involve items such as knowledge resources, human resources. The details can be founded in: Sheng-kui Cheng, 2007. Resource Flow: Theoretical Framework and Application for Decision Making, Resource Science, 29 (3): 37–44, in Chinese.

3) For the details of the classifications, calculations and applications of the resource values refer to: Zhifang Zhou, The Construction and Application of Resource Flow Accounting in Flow Manufacturing Enterprise under Recycling Economy: Experience from Chinalco, Yokohama Business Review, Forthcoming.

4) The methods mainly include Japan's LIME, JEPIX (Environmental Policy Priorities Index for Japan), MAC (Maximum—Abatement Cost method), Holland's Eco-indicator 99, Sweden's EPS (environment priority strategy), European Union's ExternE

certification and so on. LIME is LCIA methodology developed by the National Institute of Advanced Industrial Science and Technology in Japan. More details can be obtained by referring to http://www.aist-riss.jp/old/lca/cie/theme/index.html.

5) Researcher (Zhijun Feng, 2004; Jian Li, 2007) summarized the basic principles, including the scientific, availability, independent, integrity, hierarchical, simplicity, dynamics, and general principles.

6) DEA is a non-parametric method in operations research and economics for the estimation of production frontiers, which is used to empirically measure productive efficiency of decision making units (DMUs). It has been credited for not requiring a complete specification for the functional form of the production frontier nor the distribution of inefficient deviations from the frontier. DEA requires general production and distribution assumptions only. In addition, erroneous assumptions may cause inconsistency with a bias over the frontier. Therefore, the ability to alter, test and select production assumptions is essential in conducting DEA-based research. However, the DEA models currently available offer a limited variety of alternative production assumptions.

7) An artificial neural network, usually called “neural network” (NN), is a mathematical model or computational model that tries to simulate the structure and/or functional aspects of biological neural networks. It consists of an interconnected group of artificial neurons and process information using a connectionist approach to computation. In most cases, an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network during the learning phase. In more practical terms, neural networks are non-linear statistical data modeling tools. They can be used to model complex relationships between inputs and outputs or to find patterns in data.

8) This enterprise, situated in southwest in China, has more than 30 production workshops (electrolysis, casting, power supply, alloys, and fine aluminum) and 5000 employees. The main product is aluminum ingot, such as aluminum alloy, fine aluminum and highly pure aluminum. The enterprise passed various authentication processes (quality control system, measurement examination system, healthy security environmental management system). To enhance resources efficiency, energy efficiency and economic benefits, this enterprise has implemented recycling economy strategies since 2005(i.e. cleaner production).

9) Primary indicators refer to items such as eco-efficiency, cleaner production, environmental protection, material recycling, development potential and value recycling.

10) Units of energy used include J, kWh, Btu. According to the standards of IEA (international energy agency).oil equivalent: 1kgoe=10000kcal/kg=41868kJ/kg or 41.9GJ/t; coal equivalent: 1kgce=7000kcal/kg=29307kJ/kg or 29.3GJ/t. In China, 1kgce=29.3MJ/kg, so this paper adopts the standards of unit of energy above except for alternating current.

11) The value added covers financial profit, interests, tax and salary etc, and reflects the corporate social responsibility in a sustainable development under a recycling economy.

12) More information can be found in the draft of the evaluation indicator system of cleaner production for the primary aluminum industry in China (indicator systems of alumina, electrolytic aluminum, Carbon Cathode and Carbon Anode). http://www.sdpc.gov.cn/zcfb/zcfbgg/gg2006/t20061207_98183.htm.

Besides the evaluation indicator systems of cleaner production in the coal, plating, tires, steel, fertilizer, machinery and glass industries in China, there is also the evaluation index system of recycling economy (macro) and evaluation index system of recycling economy (Industrial Park) in China. http://xmecc.smexm.gov.cn/pic/2007814162218.doc
http://www.teda.gov.cn/cms/cms/upload/info/200711/429924/119398811872352253.doc.

13) This report has been completed by our research team in the business school of CSU. According to the requirements of the research program of the China Aluminum (group) Co., Ltd. we initially obtained the resource value information with environmental accounting (e.g. resource flow accounting, environmental cost allocation tools, MFCA) and MFA based on a related original report of electrolytic aluminum enterprise. Subsequently we obtained information from the resource analysis report (covers alumina, electrolytic aluminum, carbon cathode and carbon anode, fabricated aluminum and recycling aluminum).This paper takes the electrolytic aluminum enterprise of Chinalco as a typical example.

14) Calculations of the relative weights of third-level indicators and other unimportant items are omitted because of word limitations.

15) After 2005, this enterprise implemented various measures for environmental management:

1. raises resource productivity and product quality through advanced technology and equipment;
2. reduces initial input of resources as far as possible, and raises the ratio of resource recovery;
3. raises the ratio of water resources recycled by using a stave water supply;
4. constructs industry chain, and makes waste from upstream become raw material downstream, the waste gets progressively

less through trapezoid use, finally forms “zero emissions”.

16) Scientific Research Program China Aluminum Co., Ltd. (EIS2006CCFF08-1304).

The primary data of the indicators are shown below.

Indicator	value	Units	numerator	Denominator	Indicator	value	Units	numerator	Denominator
A1	2.010	//t	357792	178006.00	B5	0.941	%	167503.65	178006.00
A2	2113.56	kg/t.Al	1.9E+08	88560.00	B6	0.952	%	98511.06	103478.00
A3	6252	kgce/t.Al	5.5E+08	88560.00	B7	0.701	%	3.88E+08	5.54E+08
A4	14779	kWh/t.Al	1.3E+09	88560.00	B8	0.950	%	122775.15	129237.00
A5	4.627	t//	440295	95157.72	C1	0.899	%	510.61	567.97
A6	34.007	kgce//	3236029	95157.72	C2	0.000	//t	0.00	57.37
A7	13.760	M3//	1309370	95157.72	C3	0.943	%	360.23	382.00
A8	0.7093	//t.Al	62815.61	88560.00	C4	86.730	kg/t	57364.51	88560.00
B1	0.467	%	44438.7	95157.72	C5	0.000	M3//	16.87	44438.66
B2	0.054	%	5138.52	95157.72	C6	12.9	kg//	57325.87	44438.66
B3	9.820	%	5138.52	523.27	C7	0.000	kg//	21.77	44438.66
B4	0.928	%	88560.00	95431.03	C8	0.006	%	523.27	95157.72

The time interval in this paper is 1 year. /-10 thousand Yuan (RMB).

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