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**Research Article**

# Building and Application of a Circular Economy Index System Frame for Manufacturing Industrial Chain

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**Abstract:** In this study, we build a unified Circular Economy Index System (CEIS) under the condition and trend of green supply chain management based on the analysis and comparison about the features of circular economy development among each link industry of manufacturing industrial chain. The idea and way of transmitting the unified environmental management requirement along industrial chain through setting up the weight variable is put forward at the same time. Through the building and application of the above circular economy index system model on iron and steel industry and automobile industry, it shows the model is reasonable and operational.

**Keywords:** Circular economy index system, industrial chain, manufacturing industry

## INTRODUCTION

Manufacturing industrial chain includes the upper, middle and lower industries of manufacturing industry. With perspective of production chain, the upper reach industry mainly includes the mining and production of raw materials such as iron steel, nonferrous metal, building material, coal and other raw materials, which is called as the resource industry in general; the lower reach industry provides the final products for consumer such as household appliance, motor vehicle and etc; the middle reach industry produces intermediate products (primary products and industrial remanufacturing products) for the lower reach industry to supply parts or middle material, such as motor, integrated circuit plate or one carbon chemical products. So far, a lot of researches have been carried out on the circular economy or green product index system of the upper and lower reaches of manufacturing industrial chain, while research on the middle as an independent industry is much fewer. The built index system for both ends of industrial chain is independent for each other owing to different features of industries, which are classified into the different industries actually. Ye (2008) study the unlimited business opportunity for green new energy motor. Yao and Li (2000) study the partial variable weight axiom system. Chen *et al*. (2009) have a study on comprehensive evaluation of Chinese circular economy. Xiao (2010) have a research of the legal path for energy saving and emission reduction in China. Zhang *et al*. (2009) analyse the analysis of low carbon development.

However, we found out that many items in the circular economy index system or green product index system are similar. Therefore, it is necessary to conduct a unified and systematic research on them. Under the condition and trend of green supply chain management, to transmit the unified environmental management requirements along industrial chain from an end to the other should be considered as well. Based on the above view point, after analyzing and comparing the circular economy or green product index system of the upper and lower reaches of manufacturing industrial chain as well as considering the characteristics of middle reaches industry, a unified circular economic index system frame or model for the whole manufacturing industrial chain with perspective of circular economy have been built up primarily, which may reflect the transmission of environmental management at the same time.

In this study, we build a unified Circular Economy Index System (CEIS) under the condition and trend of green supply chain management based on the analysis and comparison about the features of circular economy development among each link industry of manufacturing industrial chain. The idea and way of transmitting the unified environmental management requirement along industrial chain through setting up the weight variable is put forward at the same time. Through the building and application of the above circular economy index system model on iron and steel industry and automobile industry, it shows the model is reasonable and operational.

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**Analysis on the component parts of the circular economy index system for each parts of the manufacturing industrial chain:**

**Analysis on the component parts of CEIS for the upper reach industry:** Most of the upper reach industry is energy-intensive industry (metallurgical industry, chemical industry, building material industry and power industry), which has the feature of high energy and material consumption (including water consumption) and high discharge level. Therefore, index system designed for these industries in the circular economy compose of lowering energy consumption, improving mineral resource use factor, three wastes controlling and recycling and lowering water consumption usually:

- Index of lowering energy consumption. Energy consumption includes coal and electricity consumption.
- Index of improving use factor of mineral resource. They include mining availability, recovering factor of main mineral resource and accompanying mineral, average grade of utilized mineral, comprehensive use factor of mineral resource and etc.
- Index of three wastes controlling and recycling:
  - Waste water discharge under standard and reuse
  - Dust emission under standard and retrieve; sulphur dioxide emission under standard and retrieve; carbon monoxide emission under standard and retrieve
  - Slag discharge under standard and reuse.
- Index of lowering water consumption. These include fresh water consumption amount of unit product, comprehensive water consumption and etc.

**Analysis on the component parts of CEIS for the lower and middle reach industry:** The lower and middle reach industry have the features of long industrial chain, supply chain management and continual growth of retrieving responsibility of the waste and old product. So, this industry pays great attention to the environmental management problems such as a product's life cycle (design, production, marketing, use and retrieving) green management, green supply management and product disassembling and recovery:

- **Product life cycle environmental management:** This is an analyzing model of two dimensions. In it, the horizontal axis represents each phase of life cycle; the vertical refers to the contents of environmental management in each phase.
- **Green supply chain management:** In modern society, a product's life cycle has to be completed by several firms since social labor division is more professional. This is a process of supply chain management also. Green supply chain management is to carry out the unified environmental management with perspective of supply chain.
- **Product disassembling and retrieving:** This is one of the key points to build the circular economy index system, which will include product's disassembly, retrieval, recoverability and economy.

**Review:** We see that, there are some common ideas and also differences parts about green management or environmental management between the upper, middle and lower reach industries. The common ideas are the basic patterns which are saving energy, lowering consumption, reducing discharge and recycling waste with the objective to decrease the impact of production and consumption on environment. The different parts are the degree of impact on environment and the role of basic patterns among the upper, middle and lower reach industries. In fact, the impact of the upper reach industry on ecologic environment is much greater the lower and middle reaches industry. The role of green supply chain management in the upper reach industry is relatively small owing to the short industry chain. On the contrary, green supply chain management or a product's life cycle green management is attached great importance on the research of the lower reach industry owing to the long industrial chain.

In addition, the problem of disassembling, retrieving and recycling of waste product is being emphasized more owing to the shortening of product's life cycle, a large amount of them need to be put into production as raw materials again. This reversal direction material flow promotes the relationship between the upper, middle and lower reaches industries. Thus, the upper, middle and lower reach industries, as three parts of manufacturing industrial chain, are being interrelated more and more under the linking and interacting of both positive direction and reverse direction material flow. It is another point to support the idea of building up a unified circular economy index system and embody the idea of transmitting environmental management.

## COMPARISON AMONG THE CIRCULAR INDEX SYSTEMS OF MANUFACTURING INDUSTRIAL CHAIN TO FORM INTO A UNIFIED SYSTEM

**The material flow among the manufacturing industrial chain with perspective of circular economy:** The material flow among manufacturing industrial chain with perspective of circular economy is shown in Fig. 1. In Fig. 1, the upper reach industry and the lower reach industry are connected through the middle reach industry and the vein industry to form the positive and reverse material flow. Both of the positive and reverse material flows are the components of value chain of manufacturing industry. It means manufacturing industrial chain under circular economy includes four parts. Based on Fig. 1, the key parts of circular economy in manufacturing industrial chain will be compared and analyzed and a unified CEIS is appropriate for the whole manufacturing industrial chain then.

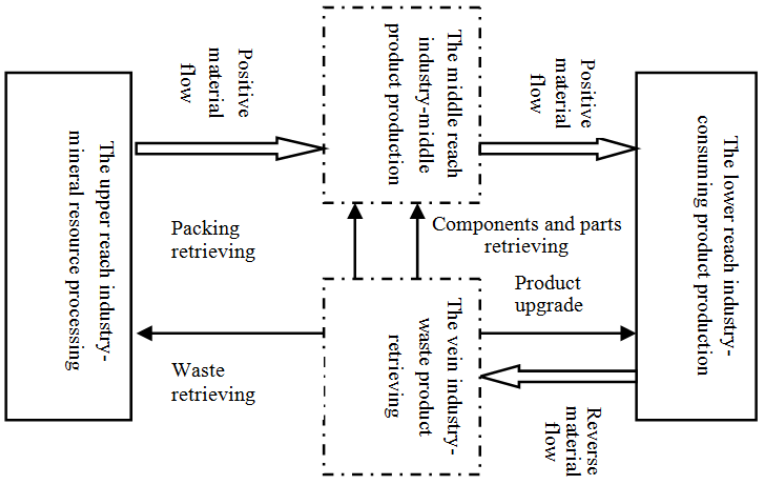


Fig. 1: Material flow chart of manufacturing industrial chain

**Comparison on the key works of circular economy among each links of manufacturing industrial chain:** The key works of circular economy construction in the upper reach industry are listed as below. The first is energy saving. The percentage of energy consumption cost over the total product cost is great, which may reach 30-50%. So, energy saving is not only the need to cut the cost of a product, but also the requirement of the construction of circular economy and low-carbon economy. The second is emission reduction. That is to reduce three wastes emission continuously, including standard compliance and recycling. The third is consumption lowering. It refers to lowering the consumption of materials, especially the consumption of ore and fresh water.

The middle reach industry is the intermediate industry to connect the upper and lower reaches industries, which is somewhat vague in conception at the moment. Generally speaking, the kinds and scale of intermediate products will be more and larger with the higher degree of specialized production and it means an improved industrialization level. The key works of circular economy construction in the middle reach industry are upgrade of intermediate products, energy saving, consumption reduction and old product recovery. For example, research and development of green energy motor is being paid great importance in many countries. Integrated circuit plate is the main part to be recovered in the vein industry since it may be used to extract rare metals and as recoverable raw material. One carbon chemical products has good value of recovery.

The key works of circular economy construction in the lower reach industry is to give overall consideration on energy saving, emission reduction, consumption lowering and product retrieving or recovery in each link of a product's life cycle.

The vein industry is to disassemble and recovery many kinds of wastes materials into raw materials of industry. This industry is being developed rapidly in the advanced industrial area and it has greater potential in future.

We can see that, the key points of circular economic work for all manufacturing industrial chain are same, which are the four basic works of energy saving, emission reduction, consumption lowering and waste reusing. However, the weight or function of each work in each industry differs greatly. The same key points are the basis to build up the unified frame of CEIS. The dissimilar working points may be reflected through choosing different circular economic index.

**A unified CEIS for manufacturing industrial chain and the component index selection:** A unified circular economic index system for manufacturing industrial chain is built up on the basis of the industrial features and achievements made. The system is composed of energy consumption, material consumption, waste disposal and recycle in production, recovery of product and packing material, green design and raw material production. The key indexes of circular economy for the four parts of industries have been selected primarily as shown in the Table 1. In the Table 1, part A and B are the basic parameters to be lowered for circular economy progress of manufacturing industrial chain; part C, D, E and F represent the controlling parameters in a product's life cycle. These parameters may be selected respectively for each reach industry.

## THE PROBLEM OF ENVIRONMENTAL MANAGEMENT TRANSMITTING CONSIDERED IN THE UNIFIED CEIS FOR MANUFACTURING INDUSTRIAL CHAIN

**Weight variable setting idea:** This problem plans to be solved through setting up the weight variable shown in the Table 1. For example, in the upper reach industry, the indexes of energy and material consumption, waste

Table 1: A unified CEIS for manufacturing industrial chain and the index selection

| Index system composition | | Weight variable | Index system for upper reach industry | Index system for lower reach industry | Index system for middle reach industry | Index system for vein industry |
|---|---|---|---|---|---|---|
| Energy consumption (A) | Electricity consumption | X1 | √ | √ | √ | √ |
| | Coal consumption | X2 | √ | | | |
| | Gas consumption | X3 | | √ | √ | |
| Material consumption (B) | Raw material consumption | X4 | √ | √ | √ | |
| | Water consumption | X5 | √ | | | √ |
| Waste disposal and recycle (C) | Waste water | X6 | √ | | | √ |
| | Waste gas | X7 | √ | | | |
| | Solid waste | X8 | √ | √ | √ | √ |
| | Waste oil | X9 | | √ | √ | |
| | Waste liquid | | | | | |
| Product and packing material discovery (D) | Old product upgrade | X10 | | √ | √ | √ |
| | Component part reuse | X11 | | √ | √ | √ |
| | Waste material reuse | X12 | √ | √ | √ | √ |
| | Packing material retrieving | X13 | | √ | | √ |
| Green design (E) | Design for disassemble | X14 | | √ | √ | |
| | Design for recovery | X15 | | √ | √ | |
| Raw material production (F) | Mineral mining | X16 | √ | | | |
| | Raw material smelting | X17 | √ | | | |
| | Raw material purchase | X18 | | √ | √ | √ |

disposal and recycle have great influence, their value of weight variable will be big then; in the middle and lower reach industry, the indexes of product and packing material recovery and product green design have great impact, so their value of weight variable will be large. The vein industry aims to retrieve, disassemble, classify and transmit wastes, so the weight of indexes of product and packing material recovery as well as the weight of electricity and water consumption, three wastes emission and treatment will not be small.

Suppose weight variable is W (X) = W {W1 (X), W2 (X), …, Wn (X)}, n is the number of index. In an industrial index system, Wi (X) ≠ 0, if it is the component part of the index system; Wi (X) = 0, if it is not the component part of the index system. Wi (X) will be bigger, if its contribution or influence is greater; Wi (X) will be smaller, if its contribution or influence is less. It means that the weight value of Wi (X) will be varied in different index system and the weight value of Wi (X) may reflect its environmental management and transmitting status along the manufacturing industrial chain (upper reach, middle reach, lower reach and vein industry). For example, the energy consumption indexes A (X) and material consumption indexes B (X) have great influence in the upper reach industry, but its influence reduce gradually along the middle reach industry and lower reach industry. Waste disposal and recycle indexes C (X) all have great influence in the three reaches industries. Product and packing material discovery indexes D (X) have great influence in the vein industry and have potential value in the lower reach industry. Green design indexes E (X) is considered only in the lower reach industry now, but it will be attached more importance gradually in the middle reach industry and upper reach industry. As to indexes F (X), there are several points to be noticed, that is, raw material production is the important part in the upper reach industry; raw material purchase is a channel to link each reach industry; purchasing environmental friendly products will meet the demand of transmitting unified environmental management.

The sum of all indicators weight is 1, that is Σ Wi (X) = 1, (i = 1, …, n). In the Table 1, the number of composed indicators is varied and the weight of the first class indexes is as below. WA = W1 + W2 + W3, WB = W4 + W5, WC = W6 + W7 + W8 + W9, WD = W10 + W11 + W12 + W13, WE = W14 + W15, WF = W16 + W17 + W18.

**Weight variable model:** Suppose the number of composed first class indexes in a CEIS for manufacturing industrial chain is n and the number of composed indicators in each first class index (second index) is m. The weight of each index or indicator as well as probability and information amount embodied differs owing to the varied index number and varied indicators number. Therefore, combination of entropy coefficient method and the partial variable weight method is used to build up a weight variable model.

According to the partial variable weight method (Yao and Li, 2000), suppose a indicator's variable weight vector Wj (X) is the Hadamard multiplication of the indicator's constant weight vector Wj and status variable weight vector Sj (X), that is, Wj (X) = WjSj (X) / [ΣWjSj (X)], j = 1, …, n. According to entropy definition, status variable weight vector (information entropy) Sj (X) = -kΣPj*ln Pj, Pj is probability. If all probability are equal, information entropy has the largest value kln n. To make 1≥Sj (X) ≥0, take k = 1/ln n. constant weight vector Wj may be obtained with specialist method or AHP method.

In this study, the composition of first class index is the same though the indicator composition of different industry is not same. That is, for the first class index, we have, Wij (X) = WijSij (X) / [ΣWijSij (X)], in it, i (first class index) = A, …, F; j (second class index) = 1, …, m.

Table 2: CEIS model application in the iron and steel industry and automobile industry

| CEIS model application in the iron and steel industry | | | |
|---|---|---|---|
| Level one indicators | Level two indicators | Constant weight vector $W_j$ | Status variable weight vector $S_j$ (X) |
| Energy consumption (A1) | Iron ore concentrate production energy consumption | 0.25 | 0.20 |
| Weight $W_{A1}$ = 0.215 | Energy consumption unit ton steel | | |
| | Energy consumption per 10,000 Yuan output value | | |
| | Residual heat recovery | | |
| | Residual pressure recovery | | |
| Material consumption (B1) | Iron ore concentrate production water consumption | 0.25 | 0.20 |
| Weight $W_{B1}$ = 0.215 | Fresh water consumption unit ton steel | | |
| | Coal consumption in blast furnace | | |
| | Metal material consumption in converter | | |
| | Coke ratio in converter | | |
| Waste disposal and recycle (C1) | Discharged volume of waste water unit product | 0.25 | 0.40 |
| Weight $W_{C1}$ = 0.430 | Emission volume of waste gas unit product | | |
| | Discharged volume of solid waste unit product | | |
| | Coal gas reuse | | |
| | Ore tailings reuse | | |
| | Industrial water reuse | | |
| | Smelting waste residue reuse | | |
| | Iron dust reuse | | |
| | Coal fly ash reuse | | |
| Product and packing material discovery (D1) weight $W_{D1}$ = 0.008 | Waste iron and steel reuse | 0.05 | 0.04 |
| Green design (E1) weight $W_{E1}$ = 0 | | 0 | 0 |
| Raw material production (F1) | Ore mining recovery rate | 0.20 | 0.16 |
| Weight $W_{F1}$ = 0.132 | Ore dressing iron recovery rate | | |
| | Lowest grade of optional iron ore | | |
| | Iron ore concentrate grade | | |
| CEIS model application in the automobile industry | | | |
| Level one indicators | Level two indicators | Constant weight vector $W_j$ | Status variable weight vector $S_j$ (X) |
| Energy consumption (A2) | Energy consumption unit product | 0.15 | 0.210 |
| Weight $W_{A2}$ = 0.180 | Energy consumption per 10,000 Yuan output value | | |
| | Assemble electricity consumption per vehicle | | |
| | Green energy ratio | | |
| Material consumption (B2) | Steel consumption per 10,000 Yuan output value | 0.15 | 0.158 |
| Weight $W_{B2}$ = 0.134 | Vehicle acceptance rate one time test | | |
| | Waste product reduction from assemble | | |
| Waste disposal and recycle (C2) | Scrape reuse | 0.25 | 0.158 |
| Weight $W_{C2}$ = 0.224 | Waste oil reuse | | |
| | Waste water reuse | | |
| Product and packing material | Components and parts reuse | 0.15 | 0.158 |
| discovery (D2) | Scrap tire reuse | | |
| Weight $W_{D2}$ = 0.134 | Components and parts remanufacturing | | |
| Green design (E2) | Product design for disassembly | 0.25 | 0.210 |
| Weight $W_{E2}$ = 0.229 | Modularization disassembly ratio | | |
| | Mechanization disassembly ratio | | |
| | Product upgrade and reuse | | |
| Raw material production (F2) | Renewable material proportion | 0.05 | 0.105 |
| Weight $W_{F2}$ = 0.028 | Environmental friend product purchase | | |

Suppose entropy value of the item i index in the first class index system is Si (X) = - 1/ln n*Σ (Pij*ln Pij), i = A, …, F, j = 1, …, m, then, the information weight of this index S'I (X) = (1 - Si (X)) /Σ (1 - Si (X)) and the revised index weight coefficient is Wi (X) = Wi S'i (X) / [ΣWiS'i (X)].

## APPLICATIONS

The iron and steel industry and automobile industry, which are the typical upper and lower reach industries, are selected to apply the model of above unified circular economy index system. It may be referred for the application in the middle reach industry and the vein industry since they are located in the positive and reverse material flow between the upper and lower reach industries.

**CEIS building for the iron and steel industry and automobile industry:** A circular economy index system is built for the iron and steel industry and automobile industry based on the above model shown in the left column and the right column of Table 2, according to their technological process and features and consulting relevant reference literatures and data.

**Weight calculation and comparison:** The constant weight vector Wj is given through specialist method and the status variable weight vector Sj (X) is given through information entropy method. To simplify the calculation of Sj (X), suppose all probability appeared are equal, that is the information entropy of each probability is equal, thus the level one information entropy is equal to the composition amount of level one index over the total amount of index system. The revised weights of each level one indicator are calculated and shown in the

Table 2 through the Hadamard multiplication of the indicator's constant weight vector Wj and status variable weight vector Sj (X) and treatment of weight sum equal to one. Comparing the weight value of level one indicators in the CEIS for the iron and steel industry and automobile industry, we see that $W_{A1}>W_{A2}$, $W_{B1}>W_{B2}$, $W_{C1}>W_{C2}$, $W_{D1}<W_{D2}$, $W_{E1}<W_{E2}$, $W_{F1}>W_{F2}$. This result is identical with quantitative judgment on the weight variable of upper and lower reach industries in CEIS of manufacturing chain. That is, compared with iron and steel industry, the weight value of the parts of Energy consumption, Material consumption, Waste disposal and recycle and Raw material production in automobile industry are less, while the weight value of Product and packing material discovery and Green design are larger. It shows that, the key points of circular construction in iron and steel industry are to lower the consumption of energy and material, reinforce waste disposal and recycle in production and improve environment friend degree of raw material production and purchase; and the key points of circular construction in automobile industry are to extend producer responsibility, reinforce waste or old product and packing material discovery and improve remanufacturing and green design level.

## CONCLUSION

Manufacturing industrial chain includes the upper, middle and lower industries of manufacturing industry in general. Under circular economy situation, the vein industry will be put into industrial chain. A unified Circular Economy Index System (CEIS) model for the whole manufacturing industrial chain has been established primarily. The four industries may build up their circular economy index system through selecting corresponding indexes and indicators. At the same time, the idea and way of transmitting the unified environmental management requirement along industrial chain through setting up the weight variable is discussed. Through case application, in which indicators in CEIS are selected and their weights are set for the iron and steel industry and automobile industry, it is proved primarily that the CEIS built for the closed manufacturing chain is reasonable and effective. Next step, more industries will be chosen for case application to deepen and improve the model building to form a comprehensive and unified CEIS for the whole manufacturing industrial chain.

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