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The Building of Papermaking Enterprise's Recycling Economy Evaluation Index System Based on Value Flow Analysis

Abstract At present, the research on circular economy has made a lot of substantive results both at home and abroad. But for the papermaking enterprise, which is the representative of the light industry, few studies have analyzed the evaluation index system of circular economy. Since the current material flow analyses have limitations that the researchers cannot calculate materials with different units. The authors take advantage of the intrinsic correlation between the basic principle of value flow analysis and circular economy, and then analyze the dynamic changes of material flow and value flow through enterprises internal production process. Considering the resource output, the authors set up the layered structure of the evaluation index system, and then preliminarily determine the index form. Next, the authors use the frequency statistics analysis method to adjust indicators, forming a preliminary index system. After that, the principal component analysis and independent analysis are applied for screening. Finally, the authors build a circular economy evaluation index system for papermaking enterprise to provide scientific guidance for the process of circular economy.

Keywords: circular economy, the papermaking enterprise, material flow analysis, value flow analysis, evaluation index system

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1 Introduction

Released by industry information network (Chichaev, 1972; Jia, 2009; Lichutina, Bogolitsyn, & Gusakova, 2012) of "2015–2020 China Papermaking Industry Research Depth and Outlook Report", which clearly pointed out that papermaking belongs to a high-polluting and high-consuming industry. Plus its industrial wastewater is the main pollution source in the world. Among them, Japan and the United States put the industrial wastewater of papermaking as one of six major pollution nuisances and five major pollution nuisances, respectively. According to the statistical data of the Ministry of Environmental Protection of the People's Republic of China, the national effluent emission was 69.54 billion tons in 2013, up 1.5% year on year. Among them, the industrial wastewater emission was 20.98 billion tons, which accounted for 30.2% of the total wastewater emission. In 41 industries investigation statistics, the wastewater emission in papermaking and paper products ranked first. The wastewater emission of the papermaking enterprise in 2011, 2012 and 2013 respectively were 3.82 billion, 3.43 billion and 2.85 billion tons. Although the wastewater discharge declined, it still accounts for a large proportion, which cannot be ignored.

Under the social background of increasingly serious environmental problems and more nervous resource energy, as the basic industry of national economy, the papermaking have to meet the market demand as well as save resource and energy as the starting point (Jung & Kutzner, 1978; Lamberg, Ojala, Peltoniemi, & Särkkä, 2012; Laurijssen, Faaij, & Worrell, 2013; Nickels, 1988; Torres, Lenon, Craperi, Wilting, & Blanco, 2011; Wainwright, 1999; Zhou & Shi, 2011). As a major environmental pollution, papermaking industry as early as 2005, was listed in the circular economy pilot, to formally carry out the circular economy model, while Germany, Japan, the United States, and other developed countries vigorously promoted clearer production technology of papermaking. Also they advocated the green product and service, and their circular economy of papermaking had become a

complete system (Kurosawa & Hashino, 2012; Pesonen, Ahola, Kurttila, Kajanus, & Kangas, 2001).

The developmental level of papermaking's circular economy plays an important role in realizing energy saving and emission reduction and protecting the environment. Considering that is necessary and needful to evaluate the level and efficiency of papermaking enterprise's economy. Such existing evaluation research is mainly focused on the macro, middle level (Hashimoto & Moriguchi, 2004; Liu, Wang, & Wu, 2005; Ma & Liu, 2007; Wackernagel, Oisto, & Bello, 1997; Zhong, Huang, Li, & Wang, 2006), and less on the micro evaluation. The more general of the index system construction, the less specific research object. The studies of specific enterprise case or field have not been deeply researched. The papermaking enterprise is lacking a concrete and feasible evaluation index system. The studies about the evaluation of papermaking's circular economy, concentrate on the environment, energy, energy saving, and emission reduction, etc. Their aim is the same as the studies of circular economy evaluation, both pursuing the minimum resources consumption and the minimum damage to environment. To a certain extent, it provides theoretical support and reference. As for the environmental efficiency or effects, some scholars amended it according to an assessment model of environment pollution of pulp and papermaking enterprise. Other scholars choose effective environmental efficiency indicators to evaluate the environmental efficiency for papermaking enterprise (Su, Yang, & Nie, 2014; Zhou & Wang, 2007). As for the energy efficiency and energy conservation and emissions reduction, the evaluation of carbon footprint has an important effect on the carbon emission reduction of the papermaking enterprise. The energy efficiency evaluation system of papermaking enterprises was built from five points of energy reuse, technological level and pollution treatment, etc. (Lin, 2012; Ma, Lu, & Zhang, 2011; Yan, Zhan, Liao, Feng & Ji, 2014). Studies of index system can indicate direction and provide reference for the evaluation of circular economy. The specific missing of circular economy's evaluation index system will directly affect the evaluation results of papermaking enterprises' cycle economic. Although this cannot propose the effective optimization plan to the activity of papermaking enterprises' cycle economic, accurately and scientifically. Therefore, it is very important to build an evaluation index system of circular economy in the papermaking enterprise.

2 Basic principles of the circular economy of papermaking enterprises and the value flow analysis

At present, the material flow analysis is the main method used to evaluate the performance of circular economy at home and abroad and it is widely used in national, regional and zone level (Chen, Shi, & Qian, 2008; Gao & Zhang, 2010; Geng & Song, 2014; Hu, Hu, & Chen, 2008; Huang, Bi, Li, Zhang, & Yang, 2008; Li & Li, 2008; Chang, Hsiao, Yu, & Ma, 2007; Moriguchi, 2007; Onishi, Kokubu, & Nakajima, 2008; Zhou & Xiao, 2013). However, the material flow analysis only provides real information, not for making unified accounting for material with different units of measurement. Other methods can make the real-time evaluation and analysis for material in the economy system, like ecological footprint, ecological efficiency, energy analysis, and so on. But it is difficult to measure and evaluate the dynamic flow situation of internal resource and value within a company. This is because of the missing of information with corresponding value, complicated model, etc. (Zhang, 2013). The value flow analysis is a new method of analyzing circular economy. It is based on the material flow analysis and then integrates other relative theories and methods into itself. With the analysis of the resource value transfer and the information of the material flow direction of the resources, the authors can analyze the amount of resource material flow in every part of the process of industrial enterprises. From the view of cost and value, this forms a resource value flow, and it can effectively overcome material flow analysis and other methods' defects (Binder, Hofer, Wiek, & Scolz, 2004; Murota, 1998; Zhou, 2010; Zhou & Jin, 2010; Zhou & Xiao, 2009).

The relationship between the value flow analysis model and the basic principles of circular economy is mainly reflected in the aspects such as cost of resource input, utilization efficiency of the resources, and waste discharge. The value flow analysis model helps the papermaking enterprises to evaluate the operation of the circular economy in every part of the process and its overall operation. Additionally it identifies the specific location of problems and discovers opportunities for performance improvement. It is obvious that the value flow analysis is an important technical support for the establishment and evaluation of the circular economy in the enterprises and an effective method for regulating the circular economy (Jin, 2012; Li & Dai, 2014; Xiao & Zhan, 2007; Xiao & Zhou, 2009; Xie, 2012).

Currently there are mainly two kinds of paper stock-fibrous plants and recycled paper. The papermaking technological process can be very simple if recycled paper is used as raw materials. This kind of process is based on the production process in which fibrous plants are used as raw materials. Therefore, the authors are here to explain the complex technological process in which plant fibers (wood pulp and non-wood pulp) are used as raw materials. The process is as follows: Firstly, process the raw materials stored in the raw material site, which means cutting, debarking, slicing, and doing other things to the raw materials according to the variety of the pulp, the production scale, and other factors. Secondly, cook the processed materials in a highly-concentrated alkaline liquid

at a high temperature, then separate the fibers from the cooking liquid and extract the waste liquid. Thirdly, use a stock washer, a filter press, and other machines to remove the alkaline liquid and waste liquid from the raw stock and then extract the clear pulp. The reason is that there is a large quantity of foreign substances such as waste liquid and dregs in the coarse pulp. Fourthly, bleach and deck the clear pulp to improve its purity and whiteness. Fifthly, make the pulp into paper.

Figure 1 shows the simplified technological process in which plant fibers are used as raw materials.

Generally speaking, the modern papermaking process mainly includes these steps such as preparation, cooking, washing, screening, bleaching, and papermaking with pulp. Based on these steps the authors divide the whole process into some points and establish a material flow center at each point (Huang & Chen, 2009; Xiong & Xiao, 2014). We can calculate the amount of resource value in each material flow center according to the forms of material flow. The process of the resource value flow is shown in *Figure 2*.

Considering different material and the value of the unit of measurement in papermaking enterprise unified, whole production process the input and output as well as the resources value flow and circulation chain division, combination and optimization. Simultaneously, combining the papermaking enterprise's material flow route, draw the value flow's direction. On the basis of the existing research on circular economy evaluation of enterprises, there are three points of resource investment, resource utilization, and resource production. These combine with the characteristics of the value flow in papermaking enterprise, integrated relate technologies and methods, build a set of evaluation index system of circular economy. This is based on value flow analysis, including a series of process, such as flow construction, index selection, and index determination.

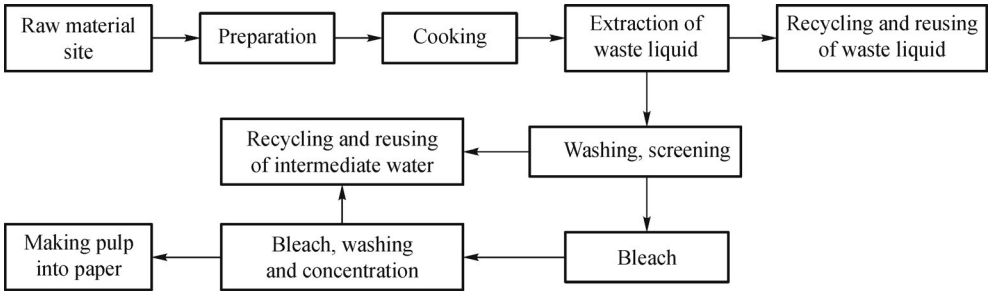

Figure 1. The production process of the papermaking enterprise in which plant fibers are used as raw materials.

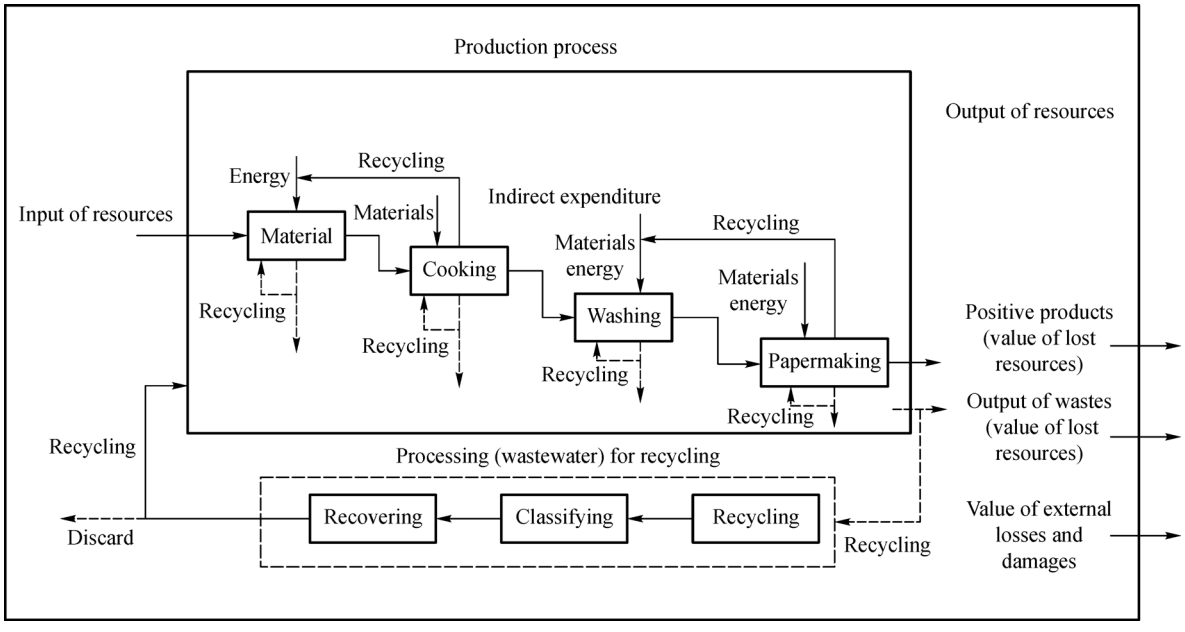

Figure 2. The resource transfer of the papermaking enterprise based on the value flow analysis.

3 The establishment of evaluation index system of the papermaking enterprise's circular economy

3.1 The concept model of evaluation index system

First, we can learn and absorb what is advanced on the evaluation of circular economy both at home and abroad, such as Japan's circular society advance planning, environmental efficiency indicators. Consider the characteristics of pulp and papermaking industry and company's key impact factors, to build the circular economy evaluation system based on value flow in papermaking enterprises. In view of this, this study selected the resource input, resource circulation index, and the resources export index as the papermaking enterprises' criterion layer of circular economy development evaluation index. In order to more specific describe the state of papermaking enterprises' circular economy development from these three aspects, the more concrete evaluation index is still needed to establish (specific index hierarchy model shown in *Figure 3*).

From *Figure 3*, the goal layer means that the purpose of establishing index system is comprehensive evaluation for circular economy of China's papermaking based on the value flow analysis; the criterion layer means the basic structure of index system; the index layer means the specific contents and attributes of the index system. The index layer contains specific indicators to directly measure the basic features of circular economy, so it need set up and screen more.

3.2 Setting up the evaluation index system

After establishing the index system of hierarchy, the authors set and ensure the specific measuring indicators of circular economy to form a complete index system. Because of the complexity of the evaluation objects and systems, the authors generally use the method of combining the qualitative analysis and quantitative analysis. One is qualitative analysis, according the evaluation's aim and principle to consider the evaluation index factors such as the necessity, feasibility, stability, and the adequacy. The second is the quantitative analysis, namely a series of inspection make the index system more scientific and reasonable.

Based on the value analysis, the evaluation of circular economy is mainly aimed at the financial management achievements of the circular economy, together with the environmental impact on the process of production and management. This adopts the eco-efficiency index form that combines the financial performance and environmental performance. Namely, the environmental indices/financial index or financial indices/environmental index formed a preliminary index system.

The following example is the choice of financial indicators. The financial indicator of the monetary unit is measurement general as the denominator of the eco-

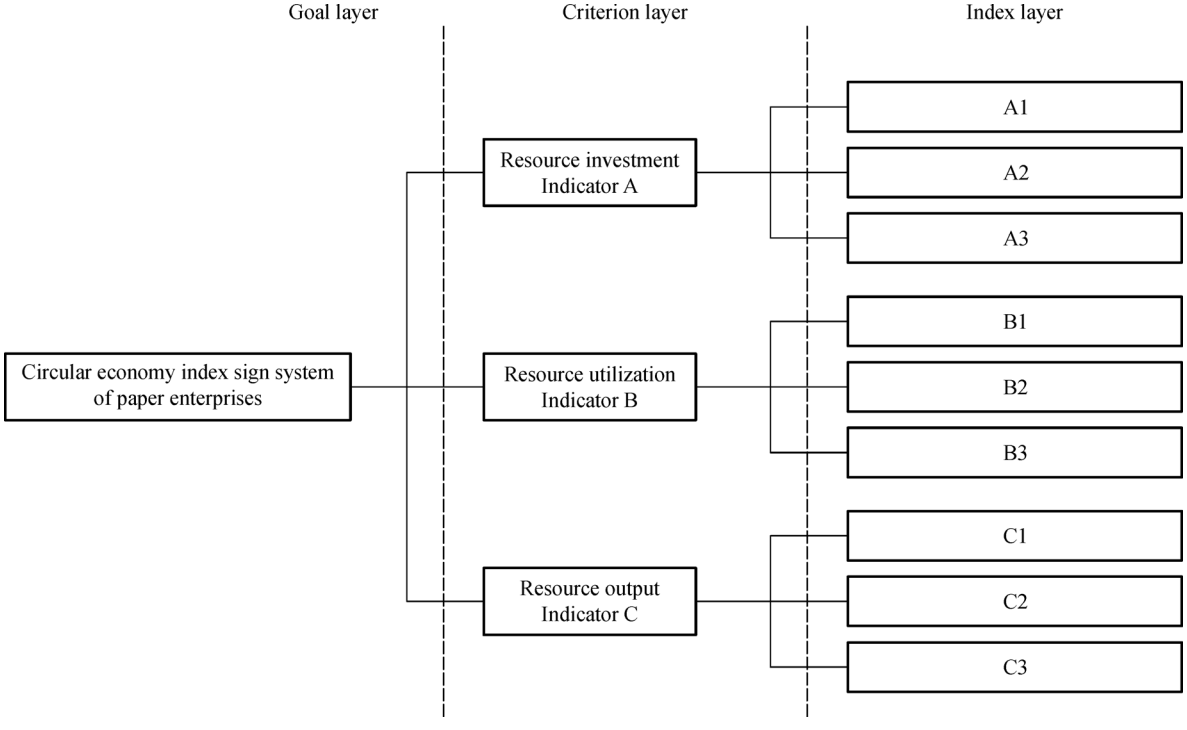

Figure 3. The hierarchy model of evaluation index system in the papermaking enterprise's circular economy.

efficiency indicators to measure industrial enterprise's certain economic benefits in the environmental performance. There are three primary financial indicators: Sales revenue, net profit, and total profit. These indicators can be obtained directly in the annual report of the industrial enterprises.

From the calculation of these indexes, the net profit is closed to the management benefit of industrial enterprise. This is because sales revenue does not deduct the cost, and the total profit does not deduct income tax, these are important factors affecting the economic benefits of industrial enterprise. So theoretically, the net profit is the most suitable financial indicator among the three indexes as the denominator of eco-efficiency indicators.

From the specific datum, the industrial enterprise's total tailpipe emissions from 2011 to 2013 were: 35,016,500 kg, 64,447,110 kg, and 71,982,570 kg. From the total tailpipe emission, 2011 was the least, 2013 was the most. The total amount of emissions is related to the scale of production, and in the evaluation of circular economy, it must combine with the economic benefit index. However, if choosing the different monetary indicators as comparison basics, there may be misleading conclusions.

According to Table 1, the economic efficiency indexes of the unit in tailpipe emission is shown in Table 2.

The index value ranking of the net profit and total profit as the denominator to calculate is 2013>2012>2011, the index value ranking according to the sales revenue is: $2013 < 2012 < 2011$ (Table 2). This means that the growth rate of sales revenue is greater than the growth rate of net profit and total profit. The resource cost is offset by the growth of economic benefits brought by the sales growth, and resource cost is the major factor causing the environmental impact of industrial enterprises.

It is only a theoretical analysis; following is the principal component analysis selecting the most typical ecological efficiency indicator.

First, get the sample data (Table 1) which is from an industrial enterprise's 2011–2013 annual report.

Second, calculate the correlation coefficient among the indicators, to get the correlation coefficient matrix (Table 3).

Third, calculate the determination coefficient of the index and the other three θ_i (Table 4).

Fourth, compare the size of θ_i in Table 4, the highest is $\theta_1 = 0.9747$, which shows that the net profit with other two indicators have the maximum correlation, so choose net profit as the main ingredient. In Table 4, r_{ij} is the correlation coefficient of index i to j, θ_i is the determination coefficient of each index and the other 3 indexes.

The primary environmental indicators include wastewater disposal rate, discharge standard-meeting rate, and emissions per unit of production. Wastewater disposal rate = the amount of wastewater disposal/output. Discharge standard-meeting rate = the amount of emissions standards/actual discharge amount. Emissions per unit of production = actual discharge amount/production.

The last is the improvement of the index. In mathematical statistics analysis, the authors usually use the principal component analysis to select the main index. According to the sample observations, the authors want to define a linear function which can represents all the differences of indexes

Table 1

Related Financial Indicators of an Industrial Enterprise in 2011–2013 Unit: CNY

Year	Sales revenue	Net profit	Total profit
2011	15,779,146.56	1,301,026.45	1,870,773.38
2012	12,660,836.15	1,266,552.90	1,831,077.36
2013	5,863,806.03	939,523.14	1,358,645.80

Table 2

Eco-Efficiency Index Unit: CNY

Year	Emissions/net profit	Emissions/sales revenue	Emissions/total profit
2011	55.33	4.56	37.87
2012	50.88	5.09	35.20
2013	37.27	5.97	25.77

Table 3

The Correlation Coefficient Matrix

Index	Net profit	Sales revenue	Total profit
Net profit	1.0000	0.9746	0.9999
Sales revenue	0.9746	1.0000	0.9707
Total profit	0.9999	0.9707	1.0000

Table 4

Determination Coefficient Calculation

i	r^2_{ij}			$\sum(r^2_{ij})$	θ_i
	$j=1$	$j=2$	$j=3$		
1	1.0000	0.9498	0.9997	2.9495	0.9747
2	0.9498	1.0000	0.9422	2.8920	0.9460
3	0.9997	0.9422	1.0000	2.9419	0.9709

in the sample as the main ingredients. To meet the requirements of the independence of the indicators, it needs independence analysis. By calculating the correlation coefficient of the selected indicators and establishing the correlation coefficient matrix, finally the authors can obtain the satisfied requirements of the index system.

3.3 The ascertainment of the evaluation indices

After the ascertainment of the index form, the primary selection of indices, and the improvement of the index system, it defines the layered structure which includes object evaluation, control evaluation and indicator evaluation. Through consulting and collecting the relevant information of the papermaking enterprise, 64 evaluation indices are determined. This is achieved using frequency statistics, theoretical analysis, and Delphi method. Its primary indices include economic benefits, environment protection, material flow, value flow, and so on. In the process of the index selection, 24 indices are deleted for they do not meet with the feasibility and accuracy. 18 indices are excluded after completing principal component analysis (PCA) and the independence analysis, and 22 evaluation indices are eventually left. Comprehensive evaluation index of resource circulation in the papermaking enterprise, which is finally determined after the adjustment, is shown in Table 5 (Chen, Fu, & Cao, 2012; Chen, Lai, & Chen, 2005).

Table 5 shows the following details:

(1) Resource input index. Integrated resource output rate mainly refers to the total industrial output value or general income (in constant calculation) in papermaking enterprises' once resource (including: Wood, alkali, etc.) consumption. Major integrated resource per unit consumption refers to the resource consumption of wood, water, and other major resources per unit product, reflecting the use intensity of primarily resources. Wood investment per unit output value refers to the amount of wood consumed by per unit product. The formula is: Wood investment per unit product = wood investment/total amount of production. Water (coal, electricity) consumption per unit output value refers to the amount of water (coal, electricity) resource consumed by per unit output value or profit. The formula is: Water (coal, electricity) consumption per unit output value = the amount of water (coal, electricity) consumption/total value of output. The smaller the index is, the less the water (coal, electricity) resource is consumed by the enterprise, or in the case of unchanged resource consumption, enterprises creates more per unit output value. Material investment cost per unit product is the cost of material consumed by per unit product, the formula is: Material investment cost per unit product = material investment cost/total output. Comprehensive cost per unit output value refers to material, energy, labor, and system cost consumed by per unit product. The greater the index is, the higher the level of the repeated use of lignin is, which means it has little impact on the environment.

(2) Resource utilization index. Water resource reuse efficiency refers to the proportion of repeated water consumption in the total water consumption as a whole in papermaking industry. Lignin utilization efficiency refers to the proportion of the repeated utilization of lignin in the total output of lignin as a whole in the paper production process. This is because of the long time span of natural degradation of lignin, the discharge has a negative effect on the environment. Black liquor extraction efficiency refers to the proportion of the evaporated solids in the steam cooked solids as a whole. The increase of black liquid extraction efficiency is not only the key of alkali recovery and comprehensive utilization of waste liquor, but also the key of the energy-saving and the cost-saving of wastewater treatment in the middle section. The ratio of internal resource value and external damage value refers to the ratio of internal circulation resource value and external environmental damage value of per unit product. The internal circulation resource value inside papermaking enterprises is calculated on the basis of the material flow analysis, in accordance with the calculation model of the circulation resource value. The external environmental damage value is calculated by the LCA evaluation method (such as the LIME evaluation method). Value-added efficiency per unit output refers to the additional value ration of per unit output value. Material cost loss rate refers to the cost of material loss/total cost of major resources. This kind of index explaining the utilization efficiency of resources in the production process should be based on the value stream analysis. Comprehensive value loss rate stands for the proportion of the comprehensive value loss of resource (the loss of negative product) in the total resources value (sum of positive and negative product value) as a whole.

(3) Resource output index. Disposal cost per unit waste

Table 5

Evaluation Index System of Circular Economy in Papermaking Enterprise

Criterion layer	Index layer
Resource input index A	Integrated resource output rate A1
	Major integrated resource per unit consumption A2
	Wood investment per unit output value A3
	Water consumption per unit output value A4
	Coal consumption per unit output value A5
	Electricity consumption per unit output value A6
	Material investment cost per unit product A7
	Comprehensive cost per unit output value A8
Resource utilization index B	Water resource reuse efficiency B1
	Lignin utilization efficiency B2
	Black liquor extraction efficiency B3
	The ratio of internal resource value and external damage value B4
	Value-added efficiency per unit output B5
	Material cost loss rate B6
	Comprehensive value loss rate B7
Resource output index C	Disposal cost per unit waste C1
	Wastewater discharge per unit attachment value C2
	COD discharge per unit attachment value C3
	BOD discharge per unit attachment value C4
	SS discharge per unit attachment value C5
	External damage value per unit output C6
	Contingent liability ratio C7

refers to the cost consumption of production system in waste treatment. The consumption cost is entirely caused by waste due to its generation, disposal and discharge. Thus, this index is a pure loss, which indicates the financial impact on the enterprise brought by the generation and disposal of the waste. Wastewater (chemical oxygen demand (COD), biochemical oxygen demand (BOD), and suspended solids (SS)) discharge per unit attachment value refers to wastewater (COD, BOD, and SS) generated by per unit attachment value. External damage value per unit output refers to enterprise economic activities in the supply, production, sales, and recycling. This causes the pollution of air, water, noise, waste, and the exploitation of natural resources, and brings ecological damage and other adverse environmental problems. But the proportion of environment treatment cost in the output value is taken by society instead of enterprises. Contingent liability means that in accordance with the occurrence or not occurrence of a certain or some certain future things. It repairs the environmental damage or compensate for the obligations of the third party that are likely to be damaged by it. Contingent liability ratio = contingent liability/total indebtedness.

4 Conclusions

Based on the basic principle through material recycle, circular economy can create more value; the authors took material flow of papermaking enterprises as a route, combined with the change law of the material flow and value flow interaction. And by tracking and depicting the resource value flow path, the authors tried to construct a circular economy evaluation index system of papermaking enterprises from the angles of resources, resource utilization, and resource input-output. This evaluation system not only can evaluate the development of the whole papermaking enterprise cyclic economy, but also can be applied to the evaluation of Brand Company and some production line. In line with the evaluation index system, the whole or part of papermaking enterprise cyclic economy movement condition could be evaluated by suitable fuzzy appraising methods, such as permutations polygon comprehensive situation and insufficient of the development of cyclic economy. Tracing the last results of the analysis and top the potential of the cyclic economy changes, provide enterprise cyclic economy promotion with a scientific basis. In addition, although the research object lies in the papermaking enterprise, the index system can also provide a reference for other enterprises and industries.

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