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Accounting of External Environmental Cost of Enterprise Based on Integration of MFCA and LIME

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China's ecosystem is facing unprecedented challenges under the global context of aggravating environmental pollution. As a way to measure the environmental cost of an enterprise, accounting of external environmental cost is now under intensive study. Based on existing literature, we integrate material flow cost accounting (MFCA) and life-cycle impact assessment method (LIME) and establish the model for the accounting of external environmental cost of an enterprise. The model is verified through application to a specific case. The results show that the integration of MFCA and LIME is an effective method for accounting of external environmental cost of an enterprise. It helps to find out the factors that need to be improved to contribute to the environmental protection and the cost structure is clarified. This provides the information necessary for the enterprise to develop towards the goals of lower energy consumption, lower pollution and lower emissions.

1. Introduction

Developed countries such as the United States, the European Union, Japan and other developed countries have introduced environmental costs into their accounting research areas, and began to try to carry out environmental cost accounting in the enterprise. Wagner Bernd and IMU (1996) developed the material flow cost accounting (MFCA); Strobel (2000) described the basic theory, accounting methods, accounting applications and other aspects of MFCA; Then he (2001) studied the flow model of traffic management and the metering of MFCA; FEA and GFEM (2003) explained the implementation details of MFCA in the "Environmental cost management guide"; Japan's economic affairs province (2001) studied all of the techniques of the environmental cost accounting, and issued the "application guide of MFCA" (2007), and introduced the MFCA in detail in four parts; Nakajima Michiyasushi and Kokubu Katsuhiko (2002) demonstrated the environmental cost accounting through the MFCA method in Japanese enterprises; Onishi , Kokubu , Nakajima (2008) researched Implementing Materal Flow Cost Accounting in a Pharmaceutical Company; Herzig , Schaltegger and Burritt (2012) Published Environmental Management Accounting : Case Studies of South-East Asian companies; The United Nations, the International Accounting Association and other organizations also introduced the MFCA, And incorporate it into the relevant manual and guide; Chinese scholars Liang Fenggang, Xie Xian first proposed material flow cost accounting; Zhen Guohong (2007) put forward the principle diagram of the material flow cost accounting; Feng Qiaogen (2008) studied on the use of MFCA with standing in the point of the environmental management; Deng Mingjun (2009) study on the use of MFCA in China; Zheng Ling (2010) studied the history of the MFCA, the basic ideas of accounting, principles and methods, then built the accounting model of MFCA; Luo Xiying (2012) considered that MFCA is the cost accounting method of material transfer from the two aspects of the quantity and value of the material; Feng Jiangtao (2013) focused on the study of the standard, and it provided reference for the research and application of MFCA theory and practice in China; Xiao Xu , Liu Sanhong (2014) analyzed Environmental Management Accounting Research Based on "Elements Flow-value Flow"; Shen Hongtao , Liao Jinghua (2014) explored the relationship of Accounting and Institutional Construction of Eco-civilization; Shi Huiqing (2012) integrated MFCA and life cycle assessment (LCA) in order to assess the cost of external damage.
MFCA can be combined with life cycle assessment (LCA) for environmental impact assessment. To implement either LCA or MFCA, we have to be clear about the concept of external environmental cost, the goal and

method of its accounting, and the feasibility of doing this. The combined approach of LCA and MFCA is a more effective measure of the external environmental cost of an enterprise. MFCA can be used to obtain the material flow data during the implementation life-cycle impact assessment method (LIME) so as to generate an exact input-output table. This study aims to construct the framework of the integration of MFCA and LIME, which is then applied to the accounting and reduction of external environmental cost of an enterprise.

2. Integration framework

The materials and energy consumed in each link are tracked by using MFCA, and thus the output table and material quantity of the quantity center are obtained. Based on these data, the environmental impact caused by each link is assessed. Then according to the measures adopted for correcting the environmental impact, the cost is classified for separate accounting. Finally, by expressing the environmental impact in monetary unit through LIME, the external environmental cost is calculated.

In MFCA, there are four sources of flow of material into a quantity center, namely, new input of material, material from the upstream quantity center, reused material and recycled material. Besides the output of positive product, there is the output of negative product divided into reused waste, regenerated waste and emitted waste (waste gas, waste water and waste solid). Suppose material *a* is input into a specific quantity center, and the above description can be converted into a mathematical model (Table 1). For the convenience of modeling, we only consider one quantity center and the input of one material *a*. The situation of several quantity centers and several materials can be inferred by summation of values of each quantity center and each material.

Take the second row in the table as an example. $X^{np}, X^{nu}, X^{nl}, S_l^n, S_g^n, S_s^n$ are the mass of newly input material *a* consumed at this quantity center in the formation of positive product, reused waste, regenerated waste and emitted waste (waste gas, waste water and waste solid), respectively. They represent the distribution of mass of newly input material *a* consumed.

Take the third column in the table as an example. $X^{np}, X^{op}, X^{up}, X^{lp}$ are the mass of newly input material *a*, material from the upstream quantity center, reused material and regenerated material consumed in producing the positive product, respectively. They represent the distribution of mass of material *a* from each source consumed in producing the positive product.

Table 1: Input-output model of the enterprise

Source of input material	Input material flow	Positiv e product	Reuse waste	Regenerate d waste	Emitted waste			Input
					Liquid	Solid	Gas	Total
Newly input material	$a(X^n)$	X^{np}	X^{nu}	X^{nl}	S_l^n	S_g^n	S_s^n	X^n
Material from the upstream quantity center	$a(X^o)$	X^{op}	X^{ou}	X^{ol}	S_l^o	S_g^o	S_s^o	X^o
Reused material	$a(X^u)$	X^{up}	X^{uu}	X^{ul}	S_l^u	S_g^u	S_s^u	X^u
Regenerated material	$a(X^l)$	X^{lp}	X^{lu}	X^{ll}	S_l^l	S_g^l	S_s^l	X^l
Total of output in each term		X^p	X^{ru}	X^{rl}	S_l	S_g	S_s	

Note: X^n is the mass of all newly input material *a* consumed within time period ΔT at the quantity center, and the meaning of other symbols can be inferred similarly.

Since China has not yet published the method and standard of MFCA, Japanese standards are adopted when calculating LIME coefficients. The table of comprehensive environmental pollution index covers 1000 pollutants contributing to 11 categories of environmental damage, including global warming, ozone layer depletion and atmospheric pollution. The amount of wastes is first normalized (unit: mass (kg), gas (m^3), electric power (kwh)). The LIME coefficients for unit mass of each pollutant are determined according to discount rate. The material mass multiplied by LIME coefficient is the environmental impact of each pollutant. The external environmental cost of each waste is calculated as shown in Table 2.

Table 2: Table of external environmental cost of wastes

Quantity center	Pollutants	Amount of pollutant (non-normalized unit)	Amount of pollutant (normalized unit)	LIME coefficient (discount rate 10%)	External environmental cost
A	a_1	X_{a1}	Y_{a1}	L_{a1}	C_{a1}
	a_2	X_{a2}	Y_{a2}	L_{a2}	C_{a2}
	……	……	……	……	……
	a_n	X_{an}	Y_{an}	L_{an}	C_{an}
……	……	……	……	……	……
N	n_1	X_{n1}	Y_{n1}	L_{n1}	C_{n1}
	n_2	X_{n2}	Y_{n2}	L_{n2}	C_{n2}
	……	……	……	……	……
	n_n	X_{nn}	Y_{nn}	L_{nn}	C_{nn}
Total		$\sum X$	$\sum Y$	—	C^{ee}

3. Explanation of the integration framework

3.1 Material mass balance equation and expression of material utilization efficiency in MFCA

According to law of conservation of mass, for newly input material *a*, the mass balance equation is expressed as follows:

$$X^{np} + X^{nu} + X^{nl} + S_l^n + S_g^n + S_s^n = X^n \tag{1}$$

Dividing the two sides of formula (1) by target output X^p,

$$\frac{X^{np}}{X^p} + \frac{X^{nu}}{X^p} + \frac{X^{nl}}{X^p} + \frac{S_l^n + S_g^n + S_s^n}{X^p} = \frac{X^n}{X^p} \tag{2}$$

Let $R^n = \frac{X^n}{X^p}$, the consumption coefficient of newly input material *a* for generating the target output. Similarly, the consumption coefficients of material from the upstream quantity center, reused material and regenerated material for producing the target output are calculated, i.e., $R^o = \frac{X^o}{X^p}$, $R^u = \frac{X^u}{X^p}$, $R^l = \frac{X^l}{X^p}$.

According to material mass balance equation, the following mass balance relations also exist for the material flow:

$$X^n + X^o + X^u + X^l = X^p + X^{ru} + X^{rl} + S_l + S_g + S_s \tag{3}$$

That is, the total input of mass of each material is equal to the total output of mass of each material.
For the material flow of negative product, or the material flow of non-target product:

$$X^q = X^{ru} + X^{rl} + S_l + S_g + S_s \tag{4}$$

X^q in formula (4) is the mass of material *a* consumed in producing negative product. The total mass of material consumed in producing non-target products is equal to the sum of mass of reused material, regenerated material and emitted material.

Dividing the two sides of formula (4) by $(X^n + X^o + X^u + X^l)$,

$$1 = \frac{X^p}{X^n + X^o + X^u + X^l} + \frac{X^{ru}}{X^n + X^o + X^u + X^l} + \frac{X^{rl}}{X^n + X^o + X^u + X^l} + \frac{S_l + S_g + S_s}{X^n + X^o + X^u + X^l} \quad (5)$$

In formula (5), let $a^p = \frac{X^p}{X^n + X^o + X^u + X^l}$, the overall utilization efficiency of all input material *a*, i.e., the formation rate of positive product; let $a^{ru} = \frac{X^{ru}}{X^n + X^o + X^u + X^l}$, the waste reutilization rate of material *a* contained in the negative product. Let $a^{rl} = \frac{X^{rl}}{X^n + X^o + X^u + X^l}$, the regeneration rate of material *a* contained in the negative product; let $a^s = \frac{S_l + S_g + S_s}{X^n + X^o + X^u + X^l}$, the formation rate of emitted waste from material *a* in the negative product.

The formation rate of emitted waste a^s deserves most attention from the enterprise. The larger the value, the more severe the resources consumption and wasting is. However, this part of cost is hidden in conventional accounting method.

3.2 Expression of external environmental cost through LIME

(1) External environmental cost associated with waste regeneration

For regenerated material *a* contained in the waste, there is the following mass balance equation:

$$X^{ru} = X^{nu} + X^{ou} + X^{uu} + X^{lu} \quad (6)$$

$$C^{a1} = Y^{a1} \cdot L^{a1} \quad (7)$$

From (6) and (7), there is

$$C_a^{ru} = Y_a^{ru} \cdot L_a = (Y_a^{nu} + Y_a^{ou} + Y_a^{uu} + Y_a^{lu}) \cdot L_a \quad (8)$$

In formula (8), Y_a^{ru} is the amount of regenerated material *a* after normalization of X^{ru} by LIME; C_a^{ru} is the external environmental cost associated with the regeneration of material *a*.

(2) External environmental cost associated with waste regeneration

For regenerated material *a* contained in the waste, there exists the following mass balance equation:

$$X^{rl} = X^{nl} + X^{ol} + X^{ul} + X^{ll} \quad (9)$$

$$C^{a1} = Y^{a1} \cdot L^{a1} \quad (10)$$

From (9) and (10), there is

$$C_a^{rl} = Y_a^{rl} \cdot L_a = (Y_a^{nl} + Y_a^{ol} + Y_a^{ul} + Y_a^{ll}) \cdot L_a \quad (11)$$

In formula (11), Y_a^{rl} is the amount of regenerated material *a* after normalization of X^{rl} by LIME; C_a^{rl} is the external environmental cost associated with the regeneration of material *a*.

(3) External environmental cost associated with emitted waste

For material *a* contained in emitted waste, there exists the mass balance equation as follows:

$$S = S^n + S^o + S^u + S^l \quad (12)$$

$$C^{a1} = Y^{a1} \cdot L^{a1} \tag{13}$$

From (12) and (13), there is

$$C_a^s = Y_a^s \cdot L_a = (Y_a^{sn} + Y_a^{so} + Y_a^{su} + Y_a^{sl}) \cdot L_a \tag{14}$$

In formula (14), Y_a^s is the amount of material *a* contained in emitted waste after normalization of S by LIME; C_a^s is the external environmental cost associated with material *a* contained in emitted waste.

(4) Total external environmental cost

The total external environmental cost associated with material *a* is equal to the sum of external environmental cost associated with material *a* regenerated, reused and emitted in the waste.

$$C_A^{ee} = \sum_n^1 C_{an} = \sum_n^1 (Y_{an} L_{an})(n = 1, 2, ..., n) \tag{15}$$

$$C^{ee} = \sum_N^A C_N^{ee} (N = A, B, ..., N) \tag{16}$$

From (15) and (16), there is

$$\begin{aligned} C_{Aa}^{ee} &= C_a^{ru} + C_a^{rl} + C_a^s = Y_a^{ru} \cdot L_a + Y_a^{rl} \cdot L_a + Y_a^s \cdot L_a \\ &= (Y_a^{nu} + Y_a^{ou} + Y_a^{uu} + Y_a^{lu}) \cdot L_a + (Y_a^{nl} + Y_a^{ol} + Y_a^{ul} + Y_a^{ll}) \cdot L_a + (Y_a^{sn} + Y_a^{so} + Y_a^{su} + Y_a^{sl}) \cdot L_a \end{aligned} \tag{17}$$

In formula (17), C_{Aa}^{ee} is the external environmental cost associated with material *a* at this quantity center.

4. Results and conclusions

By this method, the destiny of each material and the associated external environmental cost can be known. The mass balance equations for the material flow are also established. After material mass flow and cost analysis, the following conclusions are drawn:

(1) Row vector represents the mass balance equation of input and output material flow of an enterprise, based on which the utilization rate of each material can be estimated. The higher the waste production rate, the more severe the material consumption of an enterprise and the lower the resources utilization efficiency is. By calculating the waste production rate, the enterprise can identify the problems leading to waste production and therefore make efforts to improve the manufacturing process.

(2) The external environmental cost of an enterprise consists of three parts: one is the external environmental cost associated with waste reuse, calculated as the normalized mass of reused waste multiplied by LIME coefficient; the second is the external environmental cost associated with the regeneration of waste, calculated as normalized mass of regenerated waste multiplied by LIME coefficient; the third is the external environmental cost associated with emitted waste, calculated as the normalized mass of emitted waste multiplied by LIME coefficient. The last part is the most important component of external environmental cost and deserves most attention from the enterprise.

To realize sustainable development of the enterprise, the top priority is to reduce the external environmental cost. An accurate accounting of the cost is an important process based on the estimates of mass and cost of material flow in an enterprise's production. Therefore, the model for the accounting of external environmental cost through the integration of MFCA and LIME is of high application value.

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