The Life Cycle Evaluation Model of External Diseconomy of Open-loop Supply Chain

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Abstract. In recent years, with the continuous deterioration of pollution, resource space is gradually narrowed, the number of waste items increased, people began to use the method of recycling on waste products to ease the pressure on the environment. This paper adopted the external diseconomy of open-loop supply chain as the research object and constructed the model by the life cycle evaluation method, comparative analysis through the case. This paper also concludes that the key to solving the problem is to realize the closed-loop supply chain and building reverse logistics system is of great significance.

1. Introduction
Materials and products flow from upstream (material purchase) to downstream (sell) in the supply chain, end of the service life, and form the so-called open-loop supply chain.

A large amount of waste products that have lost their use value are accumulated at the end of the open-loop supply chain, if they cannot be timely disposed, which will not only cause the waste of resources but also will bring environmental pollution problems, ultimately lead to ecosystem imbalance and external diseconomy of resources and environment.

Operation process of open-loop supply chain such as figure 1: it starts from material purchase, produces the final product by manufacturing and gives them to consumers by consumer channels. After being consumed, the products flow out to the environment without control.

![Figure 1. Operation process of open-loop supply chain](image)

Therefore, regardless in the production stage or the supply chain terminal phase, exist external diseconomy. It includes the resource consumption and the environmental degradation.
External diseconomy refers to the production or activity of an economic subject has cause a loss to others, but those who have been harmed have not been compensated by the economic subject[1]. E.g: Steel plant emissions of smog and harmful gases damage the property and healthy of people around them, but the damaged people can not be compensated, this is called external diseconomy. From the perspective of environmental protection, corresponding strategies are needed to solve this problem.

China’s open-loop supply chain external diseconomy research less, lack of knowledge, and the effective way to solve the external diseconomy of the open-loop supply chain is also starting later. The external diseconomy of society that caused by terminal waste products of open-loop supply chain, it has a certain meaning by using life-cycle assessment method to calculate and evaluate.

2. Solve the strategy
The external diseconomy of open-loop supply chain not only includes the resource consumption, but also includes the environmental degradation. With the concept of sustainable development deeply rooted, the implementation of closed-loop supply chain is a good way.

Closed-loop supply chain is composed of open-loop supply chain and reverse supply chain, its essence is to turn the process of open-loop supply chain “resources- production-consumption-waste” into a closed-loop feedback cycle of “resources- production-consumption-renewable resources”[2]. In this way, it is not only to make full use of waste products, but also to reduce the waste of resources, reduce pollution emissions and reduce pollution to the environment. Therefore, reverse logistics is an essential part of closed-loop supply chain.

Reverse logistics belongs to quasi-public goods. The first, it has non-exclusive, because enterprises in the implementation of reverse logistics profit at the same time, but also bring benefits and welfare to others, society and the environment; the second, it has non-competitive, assume that the waste products is in a sufficient amount, two equal-sized enterprises to implement reverse logistics, in the operation of the same cost into the recycling of waste products, in this respect it has no competitive. Called public goods, refers to those products that are both non-exclusive and non-competitive in consumption, one of the characteristics is the ability to provide income to more than one person. Public goods have positive externalities, these are a special externality. Therefore, it determines the reverse logistics both with its own economic benefits, but also has a greater external effects.

3. Measurement method
The supply chain externality measurement methods have market value method, protection cost method, replacement cost method, life cycle assessment method and etc. The first three are measured by using monetary prices. Indirectly represents the external diseconomy of the environment; but the life cycle assessment method can directly represents the external diseconomy of the environment, to quantify and use of numbers to indicate the extent of the impact on the environment, it has convenient and intuitive features.

The life cycle evaluation method is in good agreement with the research process of this paper. Therefore, it uses the method of life cycle evaluation to measure the external diseconomy of open-loop supply chain. The calculation process is shown in Figure 2:
4. Life cycle assessment model construction

Life cycle assessment method refers to when the product, production process and production activities affect the environment, people will identify the energy and material consumed in the production process of the product and the substances discharged from the production process to the environment, quantify and base on the objective evaluation to measure the external diseconomy of the environment[3].

4.1 Constructing model

The International Organization for Standardization ISO14040 improved and regulated the basic framework of life cycle assessment, four parts included: determination of objectives and scope, list analysis, impact assessment and explanation of the results[3].

The impact assessment is one of the most important steps in the life cycle assessment process, it can directly calculate the relative size of the external economy (resource consumption and environmental pollution) caused by the two supply chains to the environment. It mainly through three steps to complete the process:

(1) Classification
It mainly related to two types of environmental impact: resource consumption and ecological impact.

(2) Characterization
The method of equivalent model is used in the process of characterization, by using the equivalent factor to unify different substances in the same environmental impact type in the list analysis. According to the list analysis, the amount of emissions of each pollutant and the equivalent of the pollutant relative to the type of environmental equivalent factor, they can get the environmental impact potential caused by this pollutant. The environmental impact potential of each type of environmental impact is equal to the sum of the potential values of all substances under this type of environmental impact, referred to as $EP(j)$. The formula is as follows:

$$ \sum_{i} EP(j) = \sum \left[ Q_i \times EF(j) \right] $$  \hspace{1cm} (1)

In the formula, $i$ —— types of pollutants; $j$ —— environmental impact types; $Q_i$ —— measured the emissions of $i$ pollutants in the $j$ types of environmental impacts; $EF(j)$ —— the equivalent factor of $i$ pollutants in $j$ types of environmental impact;

Figure 2. Calculation process of external diseconomy of opened-loop supply chain
$EP(j)$, environmental impact potential caused by the emissions of $i$ pollutants in the $j$ types of environmental impacts;

$EP(j_i)$, environmental impact potential of the $j$ type of environmental impact.

(3) Quantification

1) Data standardization

Data standardization is provide a different environmental impact type that can be compared to the size of the standard. The environmental impact benchmark for this paper is based on the per capita environmental impact potential (1990), referred to as $ER(j_{90})$:

$$ ER(j_{90}) = EP(j_{90})/Pop_{90} $$  \hspace{1cm} (2)

In the formula, $EP(j_{90})$ —— the total environmental impact potential of the $j$ type of environmental impact in 1990; $Pop_{90}$ —— China’s population in 1990;

$ER(j_{90})$ —— The $j$ type of environmental impact in 1990 affects the per capita level of potential.

1) Standardization of resource consumption types, the formula is as follows:

$$ NRC(j_i) = \frac{Q_i \times RR(j_i)}{T_{ER(j_{90})}} $$  \hspace{1cm} (3)

In the formula, $Q_i$ —— resource consumption;

$NRC(j_i)$ —— standardized value for the $j_i$ resource consumption type;

$RR(j_i)$ —— standardization basis for resource consumption.

2) Standardization of environmental pollution impact types, the formula is as follows:

$$ NEP(j_i) = EP(j_{90}) \times \frac{1}{T_{ER(j_{90})}} $$  \hspace{1cm} (4)

In the formula, $T$ —— product service period;

$NEP(j_i)$ —— standardized value of the $j_i$ type of environmental impact type.

2) Weighted assessment

In fact, weighted assessment is a permutation process, the sorted object is the relative value of each environmental impact type, it represents the size of the impact on the environment. It by using the "target distance" to determine the weights and evaluating. This paper refers to the weight of environmental impact in 2000:

$$ WF(j_i) = ER(j_{90})/ER(j_{2000}) $$  \hspace{1cm} (5)

In the formula, $ER(j_{2000})$ —— the $j$ type of environmental impact in 2000 affects the per capita level of potential; $WF(j_i)$ —— the weight of the $j_i$ type of environmental impact.

Resource consumption weighted value, the formula is as follows:

$$ WR(j_i) = NRC(j_i) \times WF(j_i) $$  \hspace{1cm} (6)

In the formula, $WR(j)$ —— weighted resource consumption potential.

Environmental impact potential weight assessment, weighted formula is as follows:

$$ WP(j_i) = NEP(j_i) \times WF(j_i) $$  \hspace{1cm} (7)

In the formula, $WP(j)$ —— weighted environmental impact potential.

The resource depletion coefficient represents the resource depletion potential after weighting, expressed in RDI; the environmental impact load represents the environmental impact potential after the weighting, expressed in EIL.

$$ RDI = \sum WR(j) = \sum [NRC(j) \times WF(j)] $$  \hspace{1cm} (8)
Resource depletion coefficient and environmental impact load can reflect the impact of the environment throughout the products life cycle, compare the impact of the two supply chains (open-loop supply and closed-loop supply chains) on the environment, through the classification, characterization and quantification of date, discuss the impact of the implementation of the two supply chains on the environment.

4.2 Case study
To 2015 a waste home appliance recycling station 10,000 tons of waste TV as the object of study (The data used in this case are derived from the 《Manual on Industrial Pollutant Generation and Emission Coefficients》 [4]).

4.2.1 Life cycle assessment of analysis on external diseconomy of open-loop supply chain

| Material Component | Copper | Iron | Aluminum | Plastic |
|--------------------|--------|------|----------|---------|
| PCB                | 14.01  | 19.47| 5.3      | —       |

(1) Determination of objectives and scope
The objective of life cycle assessment of analysis on external diseconomy of open-loop supply chain is analysis and evaluation of open-loop supply chain resources, energy use and environmental pollution emissions situation, determine the extent to which pollution emissions are harmful to the environment [5]. The scope of the study is identified as a process of discarding the open-loop supply chain terminal (The process of discarding does not require energy consumption, can negligible, the evaluation object is focused on the resource consumption and pollutant emissions of the process).

(2) Resource consumption evaluation
In the open-loop supply chain product abandonment process, subject to the life cycle index system, only consider iron, copper, aluminum and other metal resources. According to the total number of waste circuit boards and waste plastics and the proportion of metal resources (as table 1) can calculate the amount of metal resources input, finally, we can get the resource exhaustion list.

| Resource type          | Copper | Iron | Aluminum |
|------------------------|--------|------|----------|
| Resource consumption (kg/a) | 1.40×10^6 | 1.95×10^6 | 0.53×10^6 |

According to the global per capita consumption level, standardized analysis of resource consumption; according to the life cycle evaluation model algorithm, and getting the latent value of the resource consumption of the three kinds of metal resources (unit: person equivalent), weighting the potential and calculating the total resource depletion factor.

| Resource type | Resource consumption (kg/a) | Standardized benchmarks RR (kg/(person·a)) | Standardized value NRC | Available period (a) | Weighted value WR | Resource depletion coefficient (Person equivalent) |
|---------------|-----------------------------|------------------------------------------|------------------------|---------------------|------------------|-----------------------------------------------|
| Copper        | 1.40×10^6                  | 1.7                                      | 823529.41              | 36                  | 22875.82         | 23813                                         |
| Iron          | 1.95×10^6                  | 10                                       | 18932.04               | 120                 | 157.77           |                                               |
| Aluminum      | 0.53×10^6                  | 3.4                                      | 155882.35              | 200                 | 779.41           |                                               |

(3) Environmental load evaluation
Research object is the waste circuit board and waste household appliances plastic, its ingredients include C, N, S, O and other elements and heavy metals, it has decided that the types of environmental pollution on external diseconomy of open-loop supply chain are global warming, acidification, eutrophication and ecotoxicity. Due to weathering, corrosion and other natural forces resulting in waste products produce less volatile gas, so we are only consider the accumulation of solid waste and the release of heavy metals into the environment.

Refer to 《Manual on Industrial Pollutant Generation and Emission Coefficients》 for heavy metal emissions in contaminants, it can get the pollutant emission list of opened-loop supply chain.

Table 4. Pollutant emission list of opened-loop supply chain

| Pollutant | cadmium (kg/a) | chromium (kg/a) | copper (kg/a) | lead (kg/a) | mercury (kg/a) | nickel (kg/a) | zinc (kg/a) |
|-----------|----------------|----------------|---------------|-------------|----------------|---------------|-------------|
| Emission  | 143.8          | 294.2          | 483600        | 8927.43     | 7.227          | 5456.9        | 33750.4     |

According to the ecotoxicity effect of heavy metals equivalent factor (refer to 《Manual on Industrial Pollutant Generation and Emission Coefficients》), we are calculate the environmental impact potential of heavy metals, finally, we can get the environmental impact load.

4.2.2 Life cycle assessment of analysis on external diseconomy of close-loop supply chain

Table 5. Environmental impact load of opened-loop supply chain

| Environmental impact type | EP | Standardized benchmark ER | Standardized values NEP | Weights WF | Environmental impact load (Person equivalent) |
|---------------------------|----|---------------------------|-------------------------|------------|-----------------------------------------------|
| Ecotoxicity               | 97502.95 | 358 | 272.35 | 1.99 | 541.98 | 541.98 |

(1) Determination of objectives and scope

Close-loop supply chain chooses research objectives and object are the same with open-loop supply chain, the range is from the process of discarding the product to the end of the reverse logistics.

(2) Resource consumption evaluation

In the close-loop supply chain product abandonment process consider iri, copper, aluminum and other metal resources. Recycling of used products, the recovery rate of common metal resources were 90% copper, iron 49%, aluminum 92%. The resource consumption is equal to the total product of waste products and the proportion of resources (1 - recovery) of the product, we can get the resource consumption list of close-loop supply chain. Same as the open loop supply chain calculation method, finally, we get the resource depletion coefficient of closed-loop supply chain is 2426.5 person equivalent.

(3) Environmental load evaluation

Close-loop supply chain to implement reverse logistics, will take the appropriate measures (such as recycling, sorting, cleaning, burning and welding). In these processes will be accompanied by the production of waste gas, waste water and solid waste and other pollutants. Factors affecting environmental condition are as table 6:

Table 6. Pollutant emission list of opened-loop supply chain

| Pollutant | exhaust gas | Waste water | solid waste |
|-----------|-------------|-------------|-------------|
| Emission (kg/a) | CO2  | SO2  | NOx  | COD | cadmium | chromium | copper | lead | mercury | nickel | zinc |
| 6.5x10^6 | 197.82 | 67.81 | 38.15 | 0.5 | 89.03 | 128.45 | 156.87 | 0.52 | 71.12 | 234.45 |

Same as the open loop supply chain calculation method, environmental impact load for each environmental impact type can be obtained by standardizing and weighting the data, finally, we can get the environmental impact load on the ecotoxicity of closed-loop supply chain is 1.08 person equivalent.
Table 7. Environmental impact load of closed-loop supply chain

| Environmental impact type | Environmental impact potential $EP$ | Standardized benchmark $ER$ | Standardized values $NEP$ | Weighted values $WF$ | Weighted values $WP$ | Environmental impact load (Person equivalent) |
|---------------------------|-------------------------------------|-----------------------------|---------------------------|----------------------|----------------------|-----------------------------------------------|
| Ecotoxicity               | 13.42                               | 358                         | 0.04                      | 1.99                 | 1.08                 | 1.08                                          |

4.2.3 Analysis result. (1) In terms of resource consumption, the resource depletion factor of open-loop supply chain is 23813 person equivalent, the resource depletion factor of close-loop supply chain is 2426.5 person equivalent. In the case of the same conditions, the open-loop supply chain puts more pressure on the consumption of resources, the close-loop supply chain is 21386.5 person equivalent less than open-loop supply chain.

(2) In terms of environmental pollution, the environmental impact load on the ecotoxicity of open-loop supply chain is 541.98 person equivalent, but on the ecotoxicity of close-loop supply chain is 1.08 person equivalent. Contrast the data, in terms of ecological toxicity, the close-loop supply chain is 540.9 person equivalent less than open-loop supply chain.

Compared with the date, in terms of the resource consumption and ecological toxicity of environmental impact types, the close-loop supply chain is better than the open-loop supply chain. To realize the closed-loop of supply chain is the key to solve the external diseconomy of the open-loop supply chain. Therefore, in order to alleviate the external diseconomy of the open-loop supply chain, we should encourage the implementation of closed-loop supply chain, in other words, we should encourage enterprises to implement reverse logistics.

5 Conclusion
The implementation of reverse logistics can significantly improve the environmental pollution and waste of resources caused by open-loop supply chain externality, so as to better promote the development of reverse logistics, the strategy system gives some suggestion about the development of government can make the reverse logistics more actively, so as to effectively implement and to maximize to promote the optimal allocation of benefits, and achieve the balance of the ecological system of social resources.

Reference
[1] Samuelson, Nordhaus. Economics[M]. Beijing: Huaxia Press, 1999.
[2] Zhanpeng Jiang.《Environmental Engineering》. No.1. Beijing. Higher Education Press. 1999, 206-300.
[3] Suira. Yu. Jing. Tao. 《Product Life Cycle Design and Evaluation》. No.1. Beijing. Science Press. 2012, 80-83.
[4] Greenpeace organization. 《Electronic Waste Recycling in China and India: Workplace and Environmental Pollution》. United Nations Environment Program. 2005, 1-8.
[5] Nakul Sathaye, Robert Harley, Samer Madanat. Unintended environmental impacts of nighttime freight logistics activities[J]. Transportation Research Part A, 2010, 44: 642 -659.