Korean Journal of LCA
Vol. 2, No. 1, 2000, pp. 25-32

다른 생산품간의 할당절차가 LCIA 결과에 미치는 영향

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The Influences on the Results of LCIA by the Allocation Procedures between Different Products

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ABSTRACT

One of the most important and problematic subjects in LCA is how to deal with allocation in calculation. Until now, there are a lot of discussions for this problem including the statement in ISO framework. However, most of the considerations of these issues are limited to the influences of inventory phase, and dose not treat the impact assessment. The author has proposed a weighting methodology in LCIA for Japan. This paper describes the difference of the results of weighting depending on the allocation principle between primary and secondary products with case study. ISO 14041 specifies that where allocation can not be avoided, the inputs and outputs of the system should be partitioned which reflects the underlying physical relationships between different products[1]. We concentrated on the physical partitioning with utilization of mass of products in this case study. Currently, there are a lot of recycle systems. We have considered the influences on the results of weighting by the allocation procedures of material recycle and thermal recycle. The results were dependent on the allocation principles.

Keywords : allocation, LCIA weighting, material recycle, thermal recycle

요 약 문

전과정평가에 있어서 가장 중요하고 문제되는 것의 하나는 계산상에서 어떻게 할당을 다루는 것인가에 관한 것이다. 현재까지 ISO framework에 있어서 이 문제는 많은 논의가 되어 지고 있다. 그럼에도 불구하고 이런 이슈 대부분의 관심은 목록단계 상의 영향들로 제한되어 있으며 영향평가는 다루어지고 있지 않다. 저자는 일본에 대한 LCIA에 있어서 가중치 방법론(weighting methodology)을 제안하고 있다. 본 논문은 사례연구를 통해 1차 생산물과 2차 생산물들 사이의 할당 원칙에 의존한 가중치 결과들의 차이점을 설명하고 있다. ISO 14041에서는 할당이 불가피할 경우와 시스템의 투입물 및 산출물이 다른 생산물들 사이에 있어서 기본이 되는 물질의 관계들을 반영시키는 것에서 분할되는 것에 관한 설명을 하고 있다. 우리는 본 사례연구에 있어 생산물들에 있어서 물질의 이용에 대한 분할에 관하여 중점을 두었다. 현재, 많은 재활용 시스템들이 존재한다. 우리는 물질의 재이용과 열의 재이용에 관한 할당 과정들에 있어서 가중치들의 결과들에 대한 영향들을 고려하였으며 그 결과들은 할당원칙에 따라 달라진다.

I. Introduction

One of the hot topics in LCA studies is how to deal with allocation in LCA. Allocation problems are omnipresent in LCA. They are the consequence of the multiple links between production system and the definition of the system boundary. A universal allocation rules dose not exist, rather from case to case modified solutions have to be found. ISO 14041 regulate the allocation principles and states that the following stepwise procedure shall be applied[1]. As a first step, allocation should be avoided as far as possible. Dividing the unit process to be allocated into subprocesses and expanding the product system to include the additional functions have been provided. If allocation cannot be avoided, inputs and outputs of the system should be partitioned between the products that reflect the underlying physical relationships between them. Where physical relationships alone cannot be established, other relationships such as economic value are utilized for allocation. The allocation principles are also applied to reuse and recycling situations, especially for the open-loop system. Currently, a lot of reports have been published that describe how to treat with allocation problems. These researches are mainly concentrated on the effect of the result of inventory analysis by selecting allocation approach. There are few studies that consider the influences on the result of impact assessment. It is impossible to conclude that the environmental impact would be influenced in totally, even if the emission of a specific substance would not be influenced by allocation procedure. The aim of this paper is to describe the differences of the results of weighting, which is final step of impact assessment, by the allocation approaches with case study.

Ⅱ. Subject of this case study

In this study, we adopted the imaginary copy machine for this case study. In use cycle of copy machine, huge quantity of papers have been used. To produce papers, firstly, lumber is broken into chips, and the next, pulp are made from chips, and finally, paper will be produced from pulp. Most of lumber, in the first manufacturing process of making paper, are supposed to be recycled from the other primary wooden products or parts. In case this primary product is excluded from the system boundary, situations that should use the allocation procedure have come up against. Furthermore, waste recycled wood, as input in the process of making paper can not be specified into single product. This situation can be called multi-input. This makes more difficult to consider how to treat this problem.

Inventory data of copy machine were obtained by Finkbeiner et al[2]. This report conducts LCI according to ISO14040, structured using the suggestions of the ISO14040. The functional unit for this product has been supposed that 480000 papers will be copied through the life cycle. The modelled life cycle steps of the system include the demand of materials and energy for the manufacturing of the product, the manufacturing processes of the sub-assemblies and components the final assembly of the product, the use phase and finally the end of life phase without recycling aspects whereas the product is landfilled. Through the life cycle, the consumption of paper is assumed to 2400kg per one product. Landfill emissions were neglected. Machines, facilities or investments are not taken into consideration. According to the results of inventory analysis, concerning the consumption of energy, the ratio of use phase occupies 80 percentages, especially the process of producing paper account for 60 percentages of use phase. Inventory table covers more than 300 substances. The primary wooden products prior to paper are excluded from the system boundary, we have to consider that the partitioning the consumption of wood between the primary

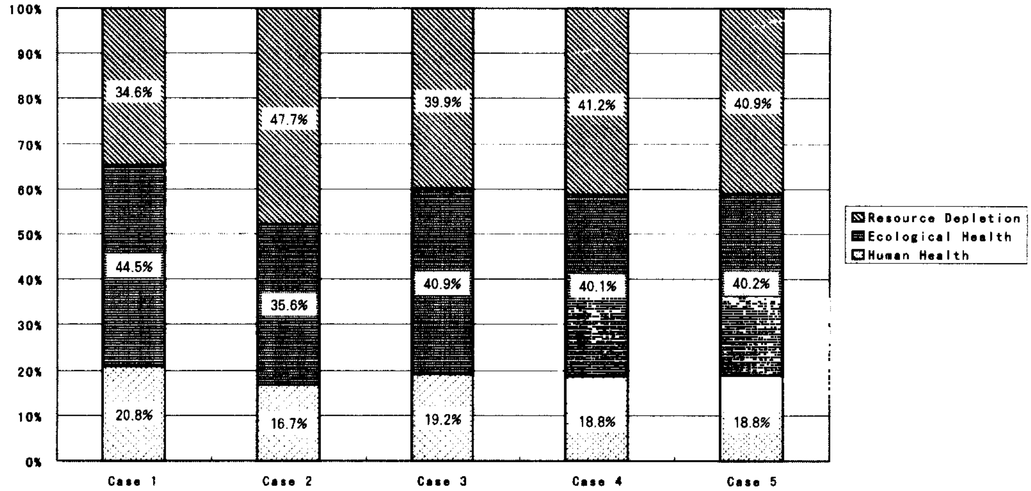

Fig. 1. System boundary of imaginary copy machine considered in this study.

products and paper. System boundary of this case study is illustrated in Fig. 1. According to PE/IKP, 4416.3kg of waste wood for recovery is consumed to produce paper.

Method

The author has been proposed the following equation for weighting across the impact categories.

$$I = \sum_s W_s D_s = W_h D_h + W_e D_e + W_r D_r$$
$$= \sum_s \left(W_{output} D_{s-output} \sum_i \left(\frac{E_i}{N_i} \times \frac{N_i}{T_i} \times R_i \right) \right) + W_{input} D_{s-input} \sum_r \left(\frac{E_r}{N_{J,r}} \times \frac{N_{G,r}}{R_r/100} \right)$$
$$= \sum_s \left(W_{output} D_{s-output} \sum_i \left(\frac{E_i}{N_i} \times W_i \times R_i \right) \right) + W_{input} D_{s-input} \sum_r \left(\frac{E_r}{N_{J,r}} \times \frac{100}{Y_r} \right) \quad (1)$$

I : Single index(%)

W_{output} : Weighting factor of safeguard subjects concerning (human health and ecosystem)

W_{input} : Weighting factor of safeguard subjects concerning input related (resources)

$D_{k-output}$: Damage of safeguard subjects (human health or ecological health) in the case that the present environmental impacts are equal to target value. (%)

$D_{k-input}$: Damage of safeguard subjects (resources) in the case that the present environmental impacts are equal to target value (%)

E_i : Incremental effects of impact category i caused by product

N_i : Normalization value of impact category i

F_i : Weighting factor of impact category i

E_r : Consumption of resource r through the life cycle of product. (ton/year)

$N_{jr,}$: Annual consumption of resource r in Japan (ton/y)

$N_{G,r}$: Annual consumption of resource r in world (ton/y)

R_r: Confirmed resource base of resource r (ton)

The characteristic of this method is to establish the simplified damage functions of impacts related with input and output, respectively. In this concept, it is important to distinguish with the comparison between impact categories and safeguard subjects. Comparisons between impact categories are proposed by the developer of a method considering political standards. Comparison between safeguard subjects can be introduced by LCA practitioner based on their goals, because this is fully dependent on the practitioners subjectivity. In this study, we applied the following relationship of the weighting across the safeguard subject based on the result of our preliminary research.

$$W_h : W_e : W_r = 0.4 : 0.4 : 0.2 \tag{2}$$

The details of this methodology are described in previous papers[3), 4), 5)].

Ⅲ. Allocation procedures

As shown above, it is difficult to clarify the primary products due to the multi-input. Consequently, it seems to be impossible to estimate the economic value of primary products, because of the values of them are quite depending on products. We concentrated on the application of physical relationship. We applied the following 5 cases of allocation procedures.

-Case 1-

In this case study, we excluded the primary products from the system boundary. If we assume that the environmental burdens were cancelled at the boundary, the consumption of wood for primary wooden products is fully assigned to primary products. This implies that the wood for primary products would not be assigned to paper. This leads that the consumption of wood for paper is counted only for that of the production of paper without the waste wood from primary products.

-Case 2-

Even though the primary products are excluded, the paper is surely made from the lumber for primary products. In this case, the consumption of wood is supposed fully assigned to secondary products, paper because of the exclusion of primary products. There is no information for the weight of primary product and the consumption of wood for primary product. We preliminary assumed that there is no loss in the process of making primary products. From the inventory table, 4416kg of wood are allocated to paper.

-Case 3-

The basic information for study is limited, however, we know the weight of wasted wood as an input (4416.3kg) for paper and consumed paper in use phase (2400kg). In this case, we assumed that the consumption of primary products and secondary product (paper) are 4416kg and 2400kg, respectively. Under this condition, allocation factor, AF_{paper} for secondary product can be calculated as follows.

$$AF_{paper} = \frac{Secondary\ Product}{Total\ Consumption} = \frac{2400}{4416.3 + 2400} = 0.352 \tag{3}$$

Consequently, the allocated consumption of wood to paper, CW_{paper} can be obtained as following.

$$CW_{paper} = Consumption\ of\ wood \times AF_{paper} = 1554.5\ kg \tag{4}$$

-Case 4-

Paper can be recycled again and again. So it is important to consider the recycle rate of paper. Recycle rate of paper is assumed as 55.3% [6)]. This rate was obtained from the aggregation of all types of paper such as imitation Japanese vellum, corrugated cardboard, newspaper and so on. The recycle rate of the kind of good quality is not so much, but 32.1%. The requirement of the quality for copy paper is higher comparatively. Consequently we adopted the latter one, 32.1% as a recycle rate for copy paper. In this case, we assume that the recycle rate is independent from the number of recycle, the total weight of product including primary product can be calculated as follows.

Total Consumption of Products

$$= \textit{Primary Products} + \textit{Secondary Products}$$
$$= 4416.3 + 2400 + 2400 \times 0.321 + 2400 \times 0.321 \times 0.321 + \cdots$$
$$= 4416.3 + \lim_{n \to \infty} \frac{2400(1 - 0.321^n)}{1 - 0.321} = 7950.9 \quad (5)$$

From this result, allocation factor for secondary product, AF_{paper} can be obtained as next function.

$$AF_{paper} = \frac{\textit{Secondary Product}}{\textit{Total Consumption}} = \frac{7950.9 - 4416.3}{7950.9} = 0.445 \quad (6)$$

Consequently, the allocated consumption of wood for paper, CW_{paper} can be obtained as follows.

$$CW_{paper} = \textit{Consumption of wood} \times AF_{paper} = 1965.3\ kg \quad (7)$$

-Case 5-

As described previously, we supposed that 32.1% of paper are recycled as paper. The rest of waste paper, 67.9% will go out from the system boundary. The waste paper will not be reclaimed directly, but incineration at least in Japan to get energy. In this case, the rest of waste paper without recycling are turned into energy by incineration.

The energy obtained by incineration of paper is supposed to 4500 calories per gram. The weight of waste paper without recycling can be calculated as following.

The weight of waste paper for thermal recycling

$$= 2400 \times 0.679 + 2400 \times 0.321 \times 0.679 + 2400 \times 0.321 \times 0.321 \times 0.679 + \cdots$$
$$= \lim_{n \to \infty} \frac{2400 \times 0.679(1 - 0.321^n)}{1 - 0.321} = 2400 \quad (8)$$

The energy requirement for producing paper and the efficiency of generation of electric power is supposed as is 9.15E+6kcal per ton and 30 percentage respectively. Under these above conditions, the weight of paper for producing from the thermal energy of wasted paper can be estimated as following.

The weight of paper that can be produced by the thermal recovery of waste paper can be obtained.

The weight of paper by thermal recovery=

$$\frac{2400 \times 4500 \times 0.3}{9.15 \times 10^6 \times 10^{-3}} = 354.1\ kg \quad (9)$$

Total consumption of products can be estimated as follows.

Total Use of products

= Primary Products + Secondary Product (Paper)+ Third Product(Thermal energy)

= 7950.9+354.1

= 8305.5kg (10)

From these results, we can obtain the allocation factor of paper.

$$AF_{paper} = \frac{8305.0 - 4416.3 - 354.1}{8305.0} = 0.426 \quad (11)$$

Consequently, the consumption of wood can be calculated.

Consumption of wood for paper

= *Total Consumption of wood* $\times$ *AFpaper*

= 1881.3kg (12)

Ⅳ. Results and Discussions

The results of weighting classified into the safeguard subjects have been compared in Fig. 2. We selected human health, ecological health and recourses as safeguard subjects. According to this Fig., the impact of human health is less than the other 2 safeguard subjects independent from the allocation principles. The case that the consum-

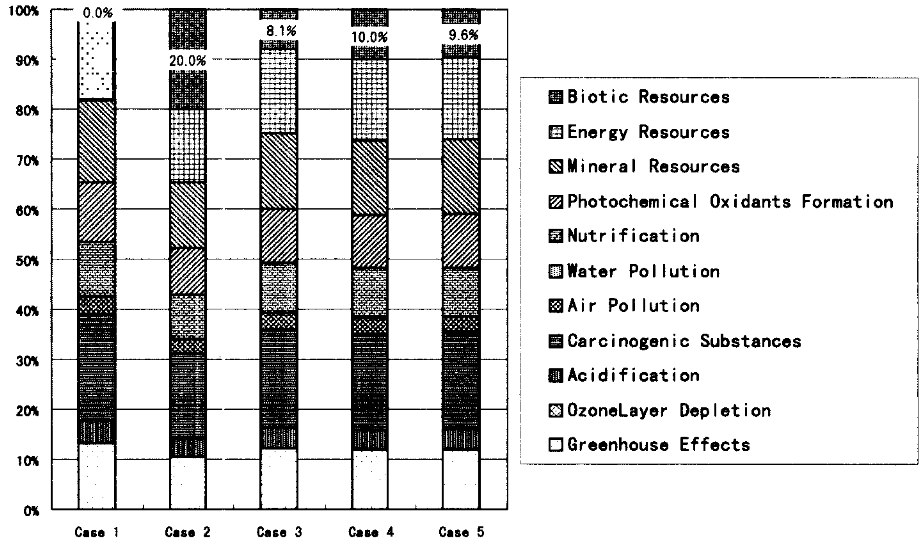

Fig. 2. Comparisons the weighting results classified into safeguard subjects by the allocation procedures. 3 subjects (human health, ecological health, resources) have been considered.

ption of wood is fully assigned to primary products, case 1 showed that the ecological health is dominant and account for about 45% of total impact. However, the case that the consumption of wood is fully assigned to secondary product, case 2 revealed that the impact of resources is dominant. The rests, Case 3, 4 and 5 revealed similar results that the contributions of ecological health and resources are almost equal. We can estimate that the allocation procedure of material recycle and thermal recycle did not affect in this comparison.

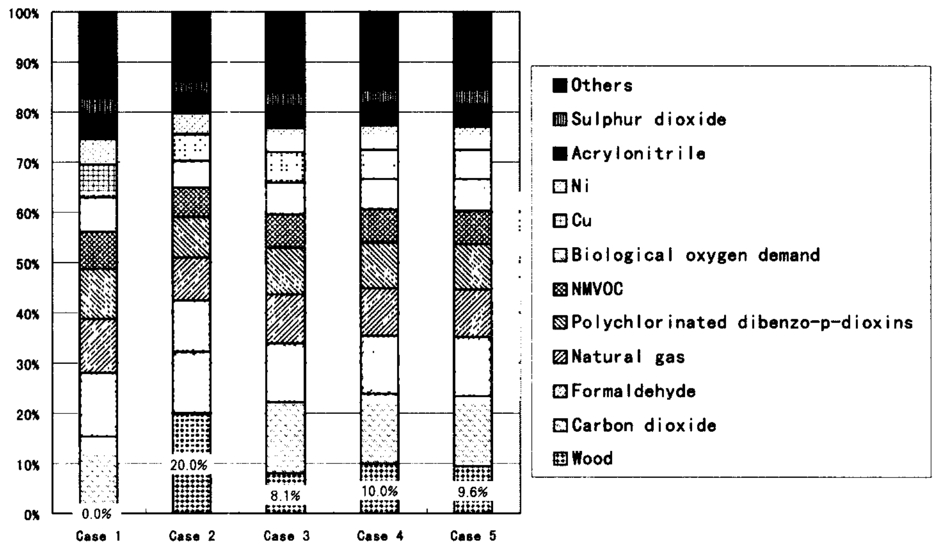

Fig. 3. Comparisons the weighting results classified into impact categories by the allocation procedures. 11 categories have been taken into account.

Fig. 3 shows the results that classified into impact categories. The compositions of biotic resources are depending on the allocation procedures. In case 2, the impact of biotic resources is the most serious and accounted for about 20%. The composition of biotic resources in Case 4 (10.0%) is about 2% higher than that of Case 3 (8.1%). This difference is due to the inclusion of the material recycling of paper. As shown in Fig. 2, Case 4, 5 revealed the similar results. They also showed that the impact of biotic resources is still important, however, the contribution of the consideration of thermal recycle does not cause large differences of results. In this study, we supposed that the recovered energy by thermal recycle is corresponding to that of the production of virgin paper. If we dont take this comparison, the result might change.

The graph in Fig. 4 illustrates the differences in the results of weighting classified into the substances in order of serious ones. The composition of wood is same as that of Fig. 3, because the impact category of biotic resource is composed by only wood. In case 2, the impact by the consumption of wood revealed the most serious. In the other cases, carbon dioxide is the most important substance in life cycle of products, however, wood is also important as much as formaldehyde, natural gas and polychlorinated dibenzo-p-dioxins. In this assessment, we considered the 68 substances and resources. This Fig. shows that the upper 11 substances account for more than 75% of total impact. To improve the provision of this assessment, it is important to look into these substances with priority that influences the total impact.

Judging from the actual recycle system, recycle rate of paper and thermal recycle would be better

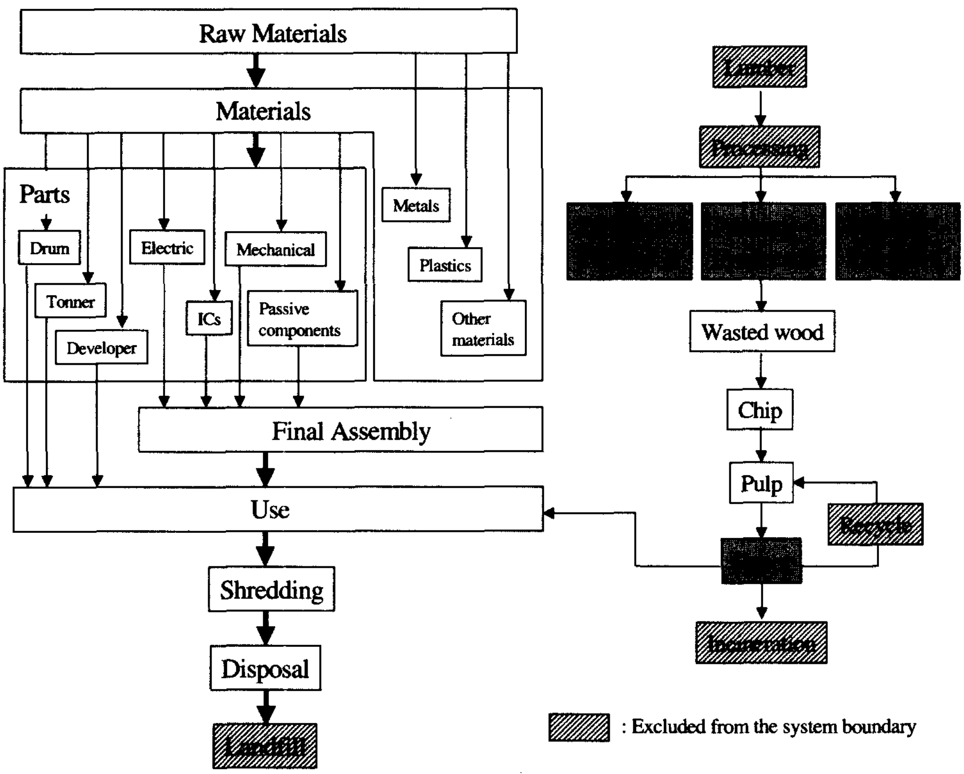

Fig. 4. Comparisons the weighting results classified into substances by the allocation procedures. Upper 11 substances are shown.

to take into consideration. This implies that case 4 and case 5 seems to be close to the real situations. However, the calculation of case 5 is performed under the condition that the value of the energy obtained by thermal recycle and that of being required for making paper is equal. The value of the primary products and secondary product also supposed to be same.

Economic partitioning between products could be argued as an effective approach to solve these problems. According to the inventory table, the paper for copy is made by plenty of wasted wood. Wasted wood is not specific product but general term. This means that it is very difficult to clarify the wasted primary products in the process for making paper, we call this process is multi-input. It is very difficult to apply the economic allocation, because the economic values of primary products are quite depending on them. In case we can include the economic aspects for allocation procedure, the allocation factor for paper may be smaller, because the primary product would be regarded as important comparatively. As a result of it, there are some possibilities that the impact of biotic resources would be estimated smaller than the results of this study.

V. Conclusion

Many studies concerning the allocation procedures have been performed. These papers discuss within the inventory analysis, and there are few investigations of the effect of impact assessment, especially for weighting results. This paper describes the differences of results for weighting due to the allocation principles with case study. Weighting procedure applied in this paper has already proposed in Japan. This method treats the both of the impact, derived from input (resource depletion) and from output (human health and ecological health). Resource depletion involves the abiotic resources (energy and mineral resources) and biotic resources.

We concentrated to use the physical partitioning without economic aspects, because the primary products are not single product. We selected a copy machine as a case study that consume a lot of paper in use phase. Currently, there are recovery systems for wasted paper such as material recycle to paper and thermal recycle to electricity at a certain degree. We considered to involve these recovery system in allocation principles. It was found that through these discussions that allocation procedures cause large differences between the results of weighting. In case allocated several products or parts are across the system boundary, it is quite important to consider how to apply the allocation procedure.

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