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Life Cycle Impact Assessment for Materials Based on the Damage Functions

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Abstract
One of the most important themes to promote Eco-design and realize the sustainable development is the establishment of the system for assessing the environmental impacts by products or materials. In recent years, many studies concern the methodologies of impact assessment to show one single index about total environmental impacts have been performed mainly in Europe. But little is known about the methodology of impact assessment for materials produced in Japan. Furthermore, the question of how to include "resource depletion" as a safeguard subject is still open. We have proposed a methodology that provides us a total indicator based on Japanese environmental problems and consumption of resources.
In this paper a research program for investigating the environmental impacts of materials produced in Japan is described. Moreover, we have applied the method to materials and discussed as a case study.
Key words: Life cycle assessment (LCA), Life cycle impact assessment (LCIA), Damage function, Safeguard subjects, Impact category

1. Introduction

There are many activities to develop the impact assessment methodologies in recent years. In Japan, many studies of LCA have been performed as case studies. However, there are few study for assessing Japanese impact assessment. As a result, to perform the impact assessment many studies used European methodologies like Eco-Indicator95 and Eco-scarcity [1,2]. This is quite dangerous, because background will differ depending on the assessed area. Furthermore, all of the methodologies developed are based on the data for developed area. Impact assessment should reflect the importances of the environmental problems in developed area. The basic data is quite different between Europe and Japan. Then if we want to assess the environmental impact in Japan, we must develop the methodology for Japan based on the data of Japanese environmental background.
The purpose of this paper is to develop the impact assessment methodology and compare with the other assessment developed in Europe to clarify the characteristic the methodology.

2. Methodology

There are quite differences between the environmental impact derived from input such as resource depletion and that from output such as greenhouse effects. SETAC Working Group showed the default list of impact categories[3]. In this list, the environmental issues are classified into the categories that relate with input and output. This methodology is based on the damage functions concerning about input and output respectively.
Figure 1 show the damage function due to emission (output). The assumptions of this function are as follows. Thresholds of the impacts are assumed to be nothing. The relationship between the effect and damage is linear. This will be the most simplified

shape of the damage function. From Figure 1, the environmental impact or damage (D_i) caused by product or material (E_i) is expressed as follows.

$$D_{output} = \sum_i D_j \times \left(\frac{E_i}{N_i} \times F_i \right) \qquad (1)$$

D_k: The damage of the safeguard subject (human health or ecosystem) when the annual effect of the impact category are supposed to target.
E_i: The increase of environmental impact by the production of object
N_i: The annual effect of the impact category i or the normalization value of the impact category i
F_i: The weighting factor of the impact category i
As shown in Eq.(1) we should define the normalization value, N_i and the weighting factor, F_i of the impact category, respectively. These values are shown in the references [4-6].
The damage function that express the relationship between the environmental impact (damage) and consumption (input) is showed in Fig. 2. If we mine the ore, the reserve of the resource will be reduced. We supposed that the damage of resources is the reduction for reserve of resource, then the relationship between the damage of the resource (D_r) and the stressor or consumption of the resource (E_r) is expressed as equation (2).

$$Dinput = \sum_r D_k \times \frac{E_r}{N_J} \times \frac{N_G}{\frac{R}{100}} \qquad (2)$$

D_k: The damage of resource r when the consumption of resource r is supposed to target (we can use the

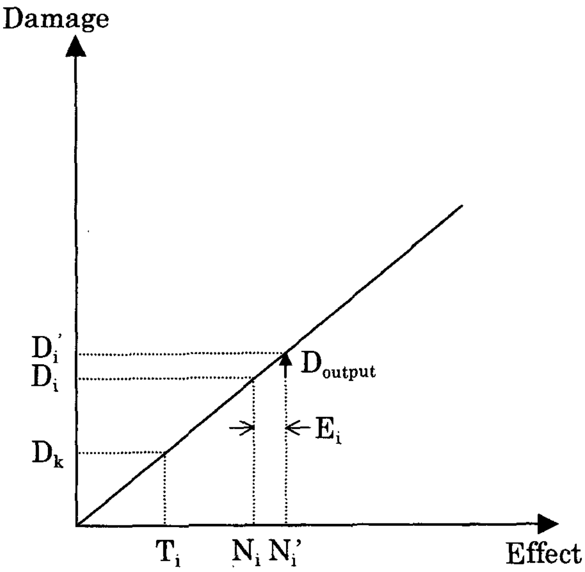

Fig.1 Damage function expressed the relasionship between the effect and the damage of safeguard subjects by the emission of environmental loading substances (output)

resource for 100 years)
E_r: The increase of consumption for resource r by the production of the object
$N_{J,r}$: The annual consumption of resource r in Japan
$N_{G,r}$: The world annual consumption of resource r
R_r: The reserve of resource r
If we assess the recycled steel that dose not need for iron ore, there is no damage concerning about the reserve of iron ore. However, the electricity will be used for production of secondary steel, and the energy resources like oil and coal will be used. As a result, the damages of energy resources will be expressed even if we make recycled materials.

	Greenhouse Effects	Human Toxicity (Air)	Nutrification	Acidification	Resource Depletion	Total
Copper	6.09E-09	8.14E-09	2.99E-08	3.05E-09	6.57E-09	5.37E-08
Zinc	1.56E-08	1.53E-08	1.62E-09	5.76E-09	1.86E-08	5.69E-08
Aluminum	1.29E-08	2.37E-08	4.63E-08	8.83E-09	2.08E-08	1.13E-07
Lead	8.50E-10	8.92E-10	1.65E-08	3.35E-10	1.33E-09	1.99E-08
Steel	1.08E-08	1.53E-08	1.19E-08	5.73E-09	7.20E-09	5.09E-08
Tin	1.24E-08	1.30E-08	2.40E-07	4.87E-09	1.93E-08	2.90E-07
Antimony	4.17E-09	4.38E-09	8.09E-08	1.64E-09	6.51E-09	9.76E-08
Cadmium	5.41E-09	5.68E-09	1.05E-07	2.13E-09	8.44E-09	1.27E-07
Tungsten	3.03E-08	3.18E-08	5.87E-07	1.19E-08	4.72E-08	7.09E-07
Molybdenum	6.31E-08	6.62E-08	1.22E-06	2.48E-08	9.85E-08	1.48E-06

Table1 The result of impact assessment for metals (copper, zinc, aluminium, lead, steel, tin, antimony, cadmium, tungsten, molybdenum). The impact categories included in this study are greenhouse effects, human toxicity, nutrification, acidification and resource depletion.

If the LCA practitioner set the goal that the result of impact assessment should be one single index, we must aggregate the impacts related with input and output. The aggregation of environmental impacts or damages is shown as follows.

$$I = \sum_k W_k D_k = W_h D_h + W_e D_e + W_r D_r$$
$$= W_{output} D_{k-output} \sum_i \frac{E_i}{N_i} F_i \qquad (3)$$
$$+ W_{input} D_{k-input} \sum_r \frac{E_r}{N_r} \times \frac{N_G}{\left(R_r/100\right)}$$

W_k: The weighting factor that show the priority of the safeguard subjects: k; h: human health, e: ecosystem, r: resources
Dk: The damage of safeguard subjects; k
The first term of right side of the equation (2) express about the impact by output. The second term show about the impact by input. As shown in equation (2), we should determine the weighting factor that compares the priority between the safeguard subjects. In this methodology, 3 items of the safeguard subjects are settled (human health, ecosystem, resources). The former 2 items are related with output categories (greenhouse effects, acidification, etc.), the latter is related to the input (resource depletion). By the calculation of the equation (2), we can get the single index that mean the total environmental impact. The weighting factor should be based on LCA practitioner's goal and subjectivity. Consequently, the result of impact assessment will depend on the practitioner. If the practitioner's goal does not accept the differences of subjectivety that compare the priorities between safeguard subjects, the impact assessment should be performed up to characterization or damage estimation.

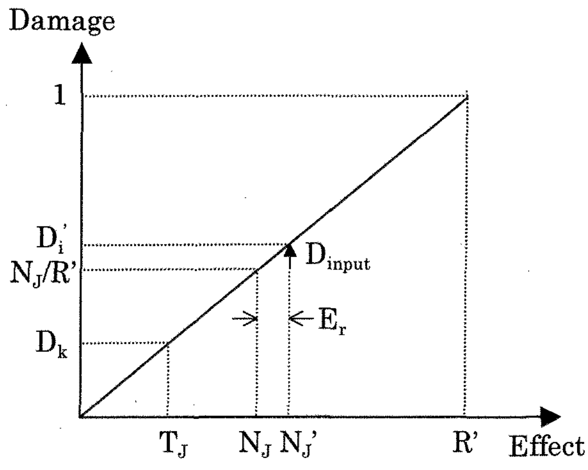

Fig.2 Damage function expressed the relasionship between the effect and the damage of safeguard subjects by the consumption of resources (input)

3. Results

In this paper, we show the result of impact assessment for 10 material (copper, zinc, aluminium, lead, steel, tin, antimony, cadmium, tungsten and molybdenum) as a case study. The scope of this study is mining the energy resources, transportation overseas, the manufacturing. The stages of disposal and transportation in Japan are excluded. The inventory data are calculated from the Japanese statistical tables.

The result of impact assessment for metals (copper, zinc, aluminium, lead, steel, tin, antimony, cadmium, tungsten, molybdenum) is shown in Table 1. The comparison between the safeguard subjects is settled that the 1% damages of safeguard subject are equal. As for steel, the impact of greenhouse effect and human toxicity are serious. The steel industry use coal and cokes as energy sources that contain S or N higher than the other resources like heavy oils comparatively. As for nonferrous material, every material, except lead the total impact are more serious than steel making. A glance at Table 1 will reveal that the impacts of Eutrophication are serious for

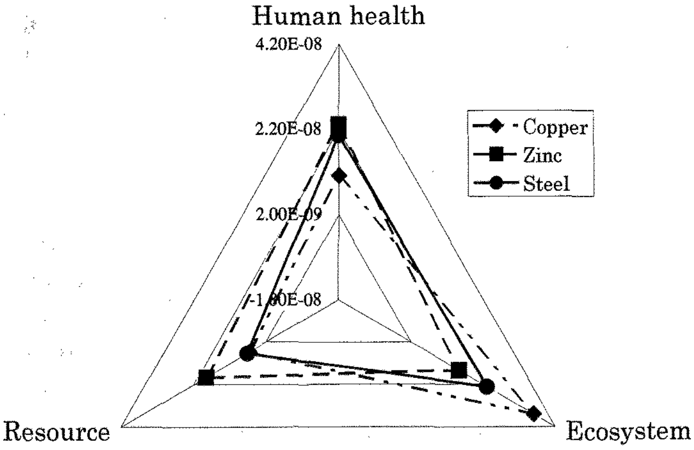

Fig. 3 The results of impact assessment for metals (copper, zinc and steel)classified into the safeguard subjects (human health, ecosystem and resources)

most materials except for zinc. For casting 1 ton metal of aluminum, 6kg dross are produced. Dross contain many impurities, especially AlN that is one of container will be the source of eutrophication. As for zinc, we see from Table1 that the impact of eutrophication is lower, but those of greenhouse effects, resource depletion and acidification are more serious. Cokes are used for deoxidization of ZnO and refining metal of zinc. The impacts related with the combustion of non-oils showed larger, because the consumption of cokes in this process are large. If the goal of LCA practitioner is to calucurate the impacts concern impact categories, the result of table 1 will be available. As shown in previously, the judgement with subjectivity will be introduced to aggregate the damages of safeguard subjects. Given that the goal of LCA is not to calculate the single index because of the subjectivity, we can show the calcurated result before aggregation to single index. Fig. 3 show the results of impact assessment for copper, zinc and steel classified into the impacts of safeguard subjects. As shown in Fig.3, the environmental impacts against the safeguard subject by material production differ depending on the safeguard subjects. Regarding the damage of human health, zinc and steel show more dangerous than copper. But concerning about ecosystem, copper is the most serious. Furthermore, as for resource, zinc show the most serious in the three metals. If we select the material from these results, the decision making depends on the priority of LCA practitioner for safeguard subjects.

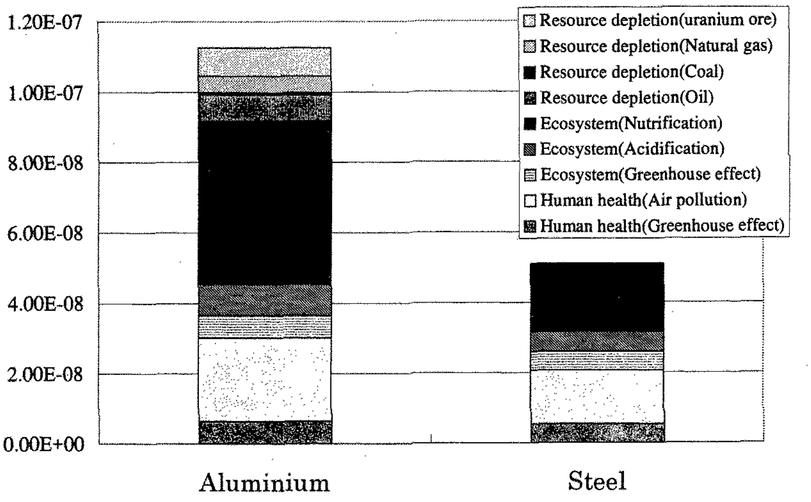

Fig.4 The comparison of impact assessment between aluminium and steel; Two types of safeguard subjects, human health and ecosystem will be influenced by greenhouse effect.

Fig.4 show the result aggregated the damages of safeguard subjects to one single-index. This figure show the comparison between aluminium and steel. Greenhouse effects are very complex problem. IPCC (Intergovernmental Panel on Climate Change) shows the survey of the effects for climate changes. In this report, the main impacts by climate changes are summarized to five categories (ecosystem, hydrology and water resources, food and fiber production, coastal system and human health). In this paper, we allocated the damages by greenhouse effect these items to 2 safeguard subjects (human health and ecosystem).

4. Conclusion

We have proposed a new methodology to assess the total environmental impacts with simplified damage functions and applied this methodology to 10 metals as a case study.

To sum up the major characteristics of this methodology, this enable to aggregate the impacts by input and output. A single index can be classified into the damage of safeguard subject respectively. The definition of the priority between the safeguard subjects depend on the goal and scope of LCA practitioner. The future directions of this study will be that the a closer investigation to define the damage functions and formation the social agreement for the relationship between the protection areas.

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