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Application of an Acid Deposition Model as a Tool for LCA Methodology

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Abstract: This research presents a new normalization method of Life Cycle Impact Assessment (LCIA), for evaluating the potential environmental impacts of a product. In the conventional LCA methodology, the normalization step normally considers the total of emission of pollutants within a period of time and within a specific area. This research focuses on a normalization step by integrating the acid deposition methodology, as a representative of the carrying capacity concept, into the conventional normalization step and compares the conventional LCA with the proposed method, so called impact index. The proposed method indicates that the carrying capacity concept renders a new perspective method and greater accuracy of the environmental impacts of a product system.

Key words: Normalization . Carrying capacity . Life cycle impact assessment . Impact index . Critical load

INTRODUCTION

The present trends of the direction that the environment, economy and society are taking have raised growing concern about their impact on current non-sustainable development. Government regulations, society's power, marketing competition and manufacturing awareness in environmental impact are rising. These have led to an increased interest in the subject of Cleaner Production (CP), Life Cycle Assessment (LCA), ecodesign or Design for Environment (DfE) and sustainable development.

The International Organization for Standardization (ISO) has published international standards on LCA. The method to achieve these consists of four main phases: (1) goal and scope definition, (2) inventory analysis, (3) impact assessment and (4) interpretation as shown in Fig. 1.

The impact assessment phase of LCA is aimed at evaluating the significance of potential environmental impacts using the result of the life cycle inventory analysis. In general, this process involves associating inventory data with specific environmental impacts and attempting to understand there impacts. The LCIA also provides information for the interpretation phase [1]. There are 4 stages of LCIA: classification, characterization, normalization and weighting. Although the normalization and weighting are the optional elements of LCIA, many researchers consider these two elements in their researches.

The core characteristic of LCA can be both its major strength and, at the same time, its limitation. One of the deficiencies of the conventional LCA method is that it does not consider time explicitly [2]. Moreover, LCIA typically excludes spatial, temporal, threshold and dose response information and combines emissions or activities over space and/or time [1]. The threshold limit of a sensitive area is representative of the carrying capacity of an ecosystem. An environmental carrying capacity is its maximum persistently supportable load [3]. Therefore, the purpose of this research is to propose a new LCIA methodology termed impact index that integrates the carrying capacity concept into LCA methodology.

MATERIALS AND METHODS

Inventory analysis: Inventory analysis involves data collection and calculation to quantify inputs and outputs of materials and energy associated with a product system [2]. An environmental load in the LCA methodology is expressed in Eq. 1. Table 1 shows an example of the data of several inventory parameters in each of five life cycle stages of the selected product.

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Table 1: Modified inventory data [4]

	Raw material acquisition	Manufacturing	Distribution	Use	End of Life
CO_2 (g fu^{-1})	168000	50300	4100	779000	-3400
CO (g fu^{-1})	840	10	60	130	-20
NOx (g fu^{-1})	510	200	60	2900	-40
SO_2 (g fu^{-1})	780	440	10	4140	-10
N_2O (g fu^{-1})	6	2	0	50	0
CFC11 (g fu^{-1})	0	30	0	180	320
CFC12 (g fu^{-1})	0	0	0	20	60

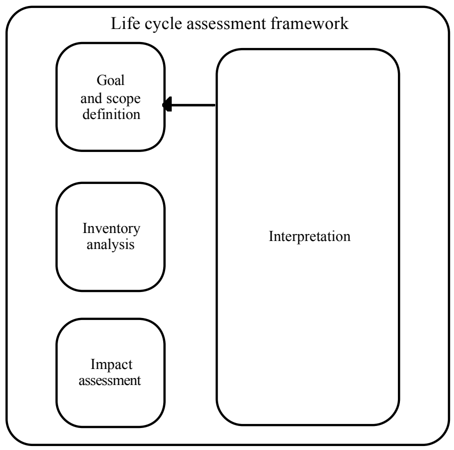

Fig. 1: Phases of an LCA [1]

$$\text{Environmental Load} = \frac{\text{Load}}{\text{fu}} \quad (1)$$

Where:

Load = Load of the inventory parameter in the product life cycle, g,
fu = Functional unit.

Characterized impact: To calculate the total contribution of the impact by inventory data to the impact category over the entire product system, the contributions of all individual emissions are totaled as shown in Eq. 2 [4]. The considered impact categories in the case study are acidification and eutrophication.

$$\text{CI} = \text{Environmental load} \times \text{eqv} \quad (2)$$

Where:

CI = Characterized impact in each impact category, g X-eq/fu,
eqv = Equivalency factor, g X-eq/g X,
X = Environmental parameter of characterization factor in each impact category.

Normalization impact

Conventional normalization impact: In the normalization step, the impact potentials are divided by the corresponding normalization references. The normalization references are calculated on the basis of an inventory of all of society's activities over a period of time [4]. The normalized impact potentials are calculated as shown in Eq. 3.

$$\text{NI} = \frac{\text{CI}}{T \times N_{ref}} \quad (3)$$

Where:

NI = Normalized impact of selected category,
T = Life time of product, time,
N_{ref} = Normalization reference, g X-eq/time.

Impact index: A grid is superimposed on the map of the selected area such as the Republic of Korea. The source, indexed i=1 and the receptors, indexed j=1, 2,…, N are defined as a grid square, as illustrated in Fig. 2. It is assumed that the amount of a unit of emission from source i reaching receptor j, a_{ij}, is distributed uniformly over the cells.

The impact magnitude (I) is defined by the Regional Air Pollution INformation and Simulation (RAINS) model as the area in which the critical load for acidification is surpassed as shown in Eq. 4 [5].

$$I = \frac{\sum A_j \times \frac{D_j}{CL_j}}{\sum A_j} \quad (4)$$

Where:

I = Impact magnitude, area,
A_j = Area at cell j, area,
D_j = Deposition at cell j, eq/area-time,
CL_j = Critical load at cell j, eq/area-time.

Critical load means a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur [6]. When pollutant loads exceed the critical load it is considered that there is risk or harmful effects.

By modifying Eq. 4 the impact index can be calculated using Eq.5, with data of the critical load and the transfer coefficient in each grid cell or interested area.

$$I = \frac{\sum A_j \times \frac{CI_j \times a_{ij}}{T \times CL_j}}{\sum A_j} \quad (5)$$

Where:

I = Impact index,
A_j = Area at cell j, area,
CI_j = Characterized impact at cell j, gSO_2 eq,
T = Life time of product, time,
CL_j = Critical load at cell j, eq/area-time,
a_{ij} = Average transfer coefficient, eq/area-mass.

RESULTS AND DISCUSSION

Relationship between carrying capacity and LCA concepts: In general, the conventional LCA method considers only the total of environmental emissions. However, nowhere is the environmental impact to the sensitive area or the threshold limit value considered. The sensitive area is related to self purification of the considered area. Therefore, the carrying capacity concept can be applied in the conventional LCA method in order to consider the environmental impact of the sensitive area.

The threshold limit of a sensitive area is representative of the carrying capacity. If the environmental load is higher than the threshold limit value, it means that the sensitive area will get a serious environmental impact, as shown in Fig. 3.

Although the total areas contained within the x-y axis curves of Fig. 3 are the same, the serious environment impacts to the sensitive areas are not the same. By the same token, if we calculated the environmental impacts by using the conventional LCA method both figures have the same LCA results. The environmental load of the left hand side figure is not higher than the threshold limit value. Therefore, this environmental emission does not have a very serious impact on the received area. On the other hand, the environmental load of the right hand side figure is higher than the threshold value. Therefore, this environmental emission does have a more serious environmental impact on the received area, especially the sensitive area.

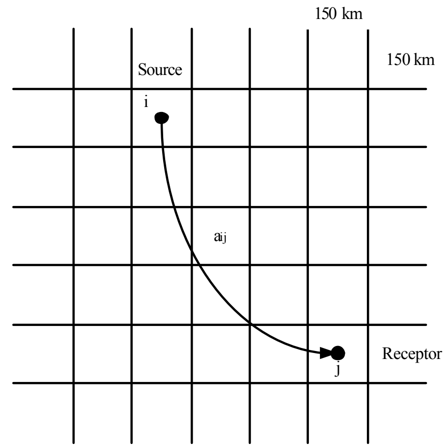

Fig. 2: Grid cells [7]

Comparison between the normalization impact and the impact index: In order to demonstrate the critical load on the environmental impact caused by the characterized impact, 11×14 km grid cell areas of the Republic of Korea with differing critical loads were chosen, as shown in Fig. 4.

The purpose of the calculation is to compare the normalization impact and the impact index of the product system in the area of interest. The impact categories considered here were acidification and eutrophication. The results of the characterization impact show that the significant issues of the selected product are the use stage of LCA from both impact categories, as shown in Fig. 5. The next step is to calculate the normalization impact. ISO14042 (2006) defines normalization as the calculation of the magnitude of indicator results relative to reference information [1]. The normalization references of acidification and eutrophication in the Republic of Korea are 2.65×10^{12} gSO_2 eq/year and 4.18×10^{11} gPO_4 eq/year, respectively [9]. The main aim of normalizing the category indicator results is to better understand the relative importance and magnitude of these results for

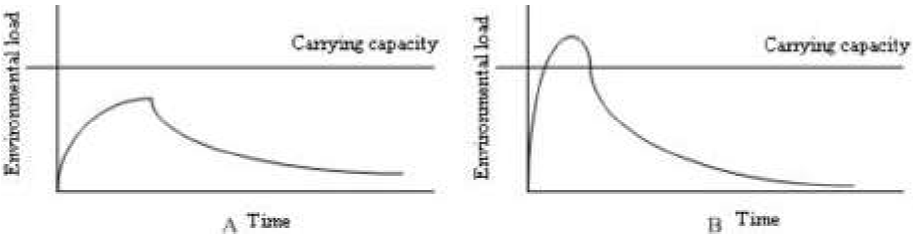

Fig. 3: Relationship between the environmental load and the threshold value

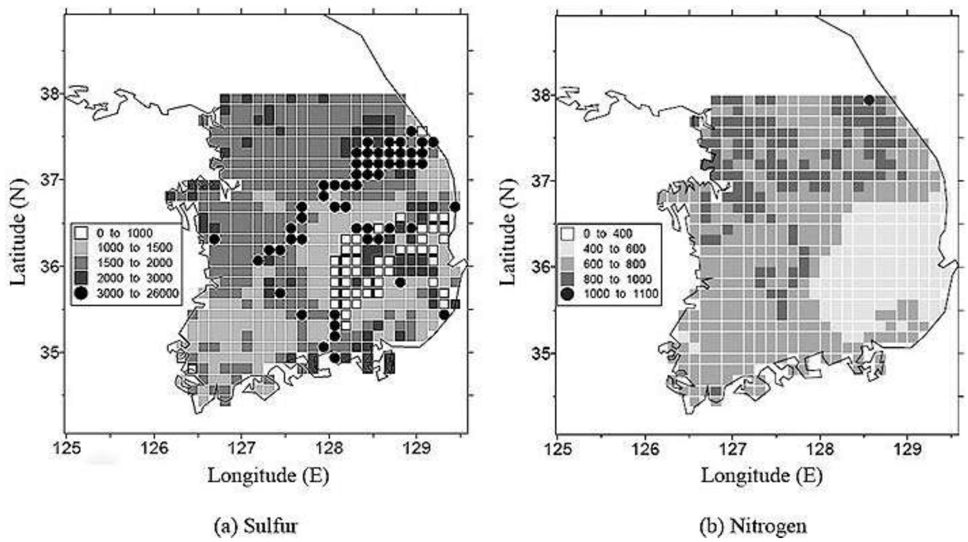

Fig. 4: Critical loads of sulfur and nitrogen in 11×14 km grid cell [8]

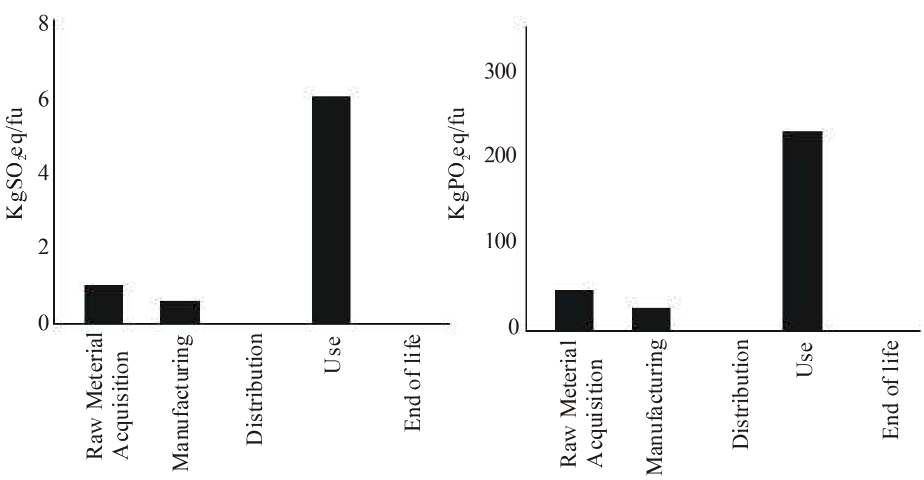

Fig. 5: Characterized impacts

each product system under study [10]. Therefore, the outcome of the normalization step reflects the proportional contribution of the product to the total impact of the same type in the region. The normalized impact of acidification and eutrophication are 2.98×10^{-9} and 7.90×10^{-10}, respectively, as shown in Fig. 6(a). These mean that the impact of acidification is higher than the impact of euthrophication by 3.8 times. On the other hand, the impact of acidification is higher than the impact of euthophication by only 2 times if the impact

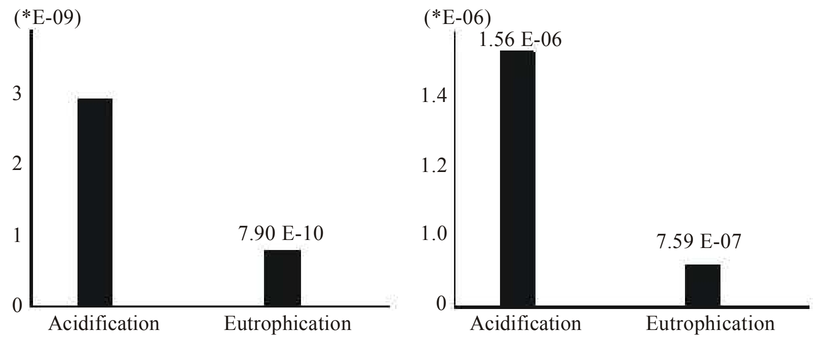

Fig. 6: (a) Conventional normalization impact, (b) Impact index

index method is used, as shown in Fig. 6(b). This difference results from the two methods being the direct results of considering the carrying capacity of the ecosystem. Moreover, these different results might affect the weighting step of the LCIA methodology and the interpretation of LCA.

Limitation of impact index: In the study, the unit transfer coefficient a_{ij} was assumed as one and environmental loads were divided by the number of grid cells of the selected area. However, in theory, the unit transfer coefficients are calculated based on measurements at monitoring points and information on emission from actual stationary sources, wind speed and precipitation. In addition, the impact index method needs much database information for other impact categories such as ozone layer depletion or photochemical oxidant creation. However, there are few relevant sub-databases available in the current main database.

CONCLUSION

The conventional LCA does not place emphasis on the carrying capacity concept. The carrying capacity consideration of the received area in the impact index would give more reasonable environmental impact results. The same amount of environmental load over the high sensitive area would more seriously affect the environment than that of the low sensitive area. The impact index can provide new insight as to the nature of ecosystem and environmental emissions of a product system by considering the carrying capacity in the area of interest.

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