◆ Application Paper

An E-score Development Methodology for Life Cycle Impact Assessment

Young-Min Park*
Jai-Rip Cho**

Abstract

This study is to make LCIA(Life Cycle Impact Assessment) easier as a methodology of environmental scores(called E-score) that integrated environmental load of each emission substance based on environmental damage such as in human health, ecosystem and resources category.

The concept is to analyzes the LCI(Life Cycle Inventory) and defines the level of environment damages for human health, ecosystem and resources to objective impact assessment standard, and makes the base of marginal damage to calculate the damage factor, which can present the indication that can establish the standard value of environmental impact.

First, damages to human health are calculated by fate analysis, effect analysis and damage analysis to get the damage factor of health effect as a DALY(Disability Adjusted Life Years) unit.

Second, damages to ecosystem are calculated by fate analysis, effect analysis and damage analysis to get the damage factor of the effect as a PDF(Potentially Disappeared Fraction) unit through linking potentially increased disappeared fraction.

Third, damages to resources are carried out by resource analysis and damage analysis for linking the lower fate to surplus energy conception to get damage factor as a MJ(Mega Joule) unit.

For the ranking of relative environment load level each other, LCIA can be carried out effectively by applying this E-score methodology to the particular emission substances. A case study has been introduced for the emission substances coming out of a tire manufacturer in Korea. It is to show how to work the methodology.

Based on such study result, product-designers or producers now can apply the E-scores presented in this study to the substances of emission list, and then calculate the environment load of the product or process in advance at any time and can see the environment performance comparatively and expected to contribute to the environmental improvement in view of environmental pollution prevention.

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* Fine Inc.
** Dept. of Industrial Engineering, Kyung Hee University

1. Introduction

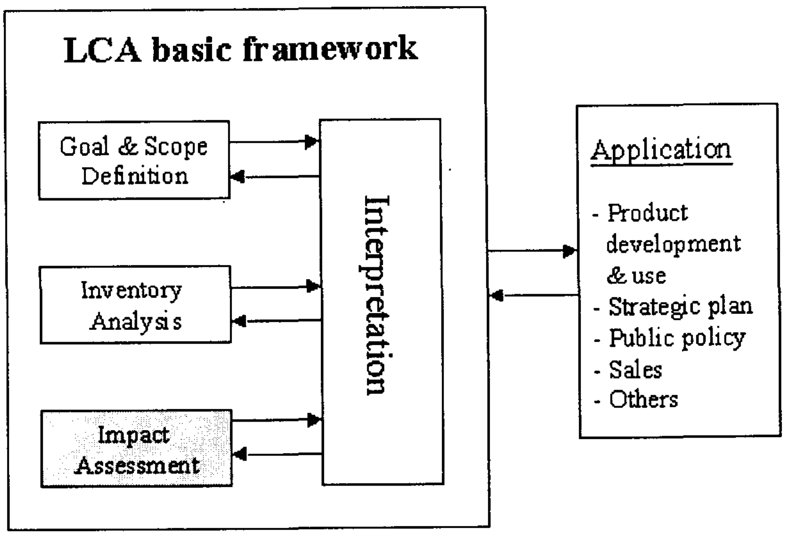
Sustainable production and consumption can only be achieved if all market actors take their own responsibility. The ultimate goal is therefore taking into account environment in every decision making process by industry, retailers and consumers.

Although LCA(Life Cycle Assessment) is a good tool to assess the environmental performance of a product, and although it is widely used by designers, LCA is time consuming and costly. Designers have to make many decisions especially when designing complex products. Moreover the results of LCA are mostly not straight forward in favour of one product or material design over the alternative one. Results of LCA have to be interpreted or weighed.

The aim is to develop a methodology of environmental score (E-score) for LCIA(Life Cycle Impact Assessment). In order to calculate such single scores a methodology is needed. This study describes a new methodology.

Background

According to ISO 14040 and 14042[10], LCIA is essentially meant to improve the understanding of the results of the inventory phase. Until now many methodologies have been suggested and described. These methodologies can be divided into theme oriented methods as ET(Environmental theme) method[8], Eco-scarcity method and EPS(Environmental priority strategies) method[21]. This study is a damage oriented method. LCA framework is as <Figure 1-1>.



<Figure 1-1> LCA basic framework [11]

Matching goal and scope with the inventory

An important aspect in any LCA is the goal and scope definition. Part of the goal and scope definition is dealing with the impact assessment. The most important requirement is that the impact assessment method suits the goal of the study.

(1) The methodology can be used as an impact assessment tool in any LCA study. This tool enables the user to determine scores for environmental damages and to aggregate them up to a single score if desired. When deciding on the degree of aggregation of damage scores to be included in this study, the user will have to take into account to what extent he wants to comply with the recommendations of ISO 14042[11] or other recommendations.

(2) The pre-calculated set of standard E-score values, consisting of a single score damage per unit of material or process, can be used as a quick tool for product development or ecological benchmarking of production processes by counting environmental load of each substances. This is essentially for internal use in companies.

The meaning of Eco

In daily life the confusion over what people consider to be an environmental problem is big. The term environment is by nature so general that almost everything can be included. Before making any sense it should be defined of the meaning environment, or what the "Eco" is.

From this definition and Dobris[5] it follows that there are basically three damage categories:

- Human Health
- Ecosystem Quality
- Resources

The three terms are not sufficiently self-explaining; a description of what is included in each of the three terms is necessary for building up the methodology.

- Human Health contains the idea that all human beings, in present and future, should be free from environmentally transmitted illnesses, disabilities or premature deaths.
- Ecosystem Quality contains the idea that non-human species should not suffer from disruptive changes of their populations and geographical distribution,
- Resources contains the idea that the nature's supply of non-living goods, which are essential to the human society, should be available also for future generations.

The following damage models is established to link these damage categories with the inventory result.

(1) Damages to Human Health are expressed as DALY (Disability Adjusted Life Years). Models are developed for respiratory and carcinogenic effects, the effects of climate change and ozone layer depletion. In these models for Human Health four sub steps are used:
- Fate analysis, linking an emission (expressed as mass) to a temporary change in concentration.
- Exposure analysis, linking this temporary concentration to a dose.
- Effect analysis, linking the dose to a number of health effects, like the number and types of cancers.
- Damage analysis, links health effects to DALYs, using estimates of the number of Years Lived Disabled and Years of Life Lost.

(2) Damages to Ecosystem Quality are expressed as the percentage of species that have disappeared in a certain area due to the environmental load. This definition is not as homogeneous as the definition of Human Health:
- Ecotoxicity is expressed as the percentage of all species present in the environment living under toxic stress[7]. As this is not an observable damage, a rather crude conversion factor is used to translate toxic stress into real observable damage.
- Acidification and eutrophication are treated as a single impact category. Here the damage to target species (vascular plants) in natural areas is modelled.

(3) Resource extraction is related to a parameter that indicates the quality of the remaining mineral and fossil resources. In both cases the extraction of these resources will result in higher energy requirements for future extraction.

A limiting assumption is that in principle all emissions are occurring in the area and that all subsequent damages occur in the area.

The weighting procedure is executed with a written panel procedure among a LCA interest group. The results can be used as a default, but should not be considered to be representative for the average. For those who do not want to use the weighting step, a new alternative approach is suggested.

2. From inventory results to damage categories

Procedures

The method uses four different procedures to establish the link between the inventory table and the potential damages:

(1) In the model for Human Health four sub-steps are used:
a) Fate analysis, linking an emission (expressed as mass) to a temporary change in

concentration.
b) Exposure analysis, linking this temporary concentration to a dose[12].
c) Effect analysis, linking the dose to a number of health effects, like the number and types of cancers, and respiratory effects.
d) Damage analysis, links health effects to the number of years lived disabled and years of Life Lost.

(2) For ecosystem two different approaches are used:
a) Fate analysis, linking emissions to concentrations
b) Effect analysis, linking concentrations to toxic stress or increased nutrient or acidity levels.
c) Damage analysis. Linking these effects to the increased potentially disappeared fraction for plants.

(3) Resource extraction is modelled in two steps:
a) Resource analysis, which can be regarded as a similar step as the fate analysis, as it links an extraction of a resource to a decrease of the resource concentration.
b) Damage analysis, linking lower concentration to the increased efforts to extract the resource in the future.

2.1 The damage category Human Health

The health of any human individual, being a member of the present or a future generation, may be damaged either by reducing its duration of life by a premature death, or by causing a temporary or permanent reduction of body functions (disabilities). According to current knowledge, the environmental sources for such damages are mainly the following[18, 19, 21, 22]:
- Infectious diseases, cardiovascular and respiratory diseases, as well as forced displacement due to the climate change.
- Cancer and eye damages due to ozone layer depletion.
- Respiratory diseases and cancer due to toxic chemicals in air, drinking water and food.

These damages represent the most important damages to Human Health caused by emissions from product systems. The damage category is not complete. For instance, damage from emissions of Cd and Pb, endocrine disrupters etc. cannot yet be modelled. Furthermore health damages from allergic reactions, noise and odour cannot yet be modelled.
To aggregate different types of damages to Human Health (which is highly desirable in view of the large number of different types of sickness), a tool for comparative weighting of disabilities is needed. This study have chosen to use the DALY (Disability Adjusted Life Years) scale, which has been developed by Murry[17] for the WHO and World Bank.

The original purpose of the DALY concept was to have a tool to analyse the rationale of national health budgets.
The core of the DALY system is a disability weighting scale. This scale has been developed in a number of panel sessions. The scale lists many different disabilities on a scale between 0 and 1 (0 meaning being perfectly healthy and 1 meaning death).

Calculation with DALYs
Carcinogenic substances cause a number of deaths each year. In the DALY health scale, death has a disability rating of 1. If a type of cancer is (on average) fatal ten years prior to the normal life expectancy, we would count 10 lost life years for each case. This means that each case has a value of 10 DALYs.

With this system, it is possible to calculate the number of Disability Adjusted Life Years if knows how many people in the area are exposed to a certain background concentration of toxic substances in air, drinking water and food.
Hofstetter[9], who has studied the use of DALYs in LCA, supplied most data for respiratory and carcinogenic effects due to chemical releases. Hofstetter also performed the calculations for climate change.

The unit for the damage category Human Health is DALY. This can easily be explained. A flow of toxic substances in tons per year will result in a number of DALY per year.

Fate analysis
Fate analysis for emissions to air, water, urban soil and industrial soil is carried out for some substances in EUSES(European Union System for the Evaluation of Substances). The three exposure pathways air (inhalation), drinking water (oral uptake) and food (oral uptake) are considered. Fate factors are calculated from the concentration in air, the concentration in drinking water and the dose by food resulting from the EUSES output[6], based on an emission of 10.000 kg/d and an emission area of $3.6*10^6$ square kilometers.
Fate factors are used to transform an emission into a concentration. For the calculation of the

fate factors the following formulas are made as an example;

$$\frac{Concentration}{Emission} = Fate\ factor$$

concentration: mg/m^3 in air
emission: $(mg.y^{-1})/m^2$
fate factor: $(m^2.y)/m^3$

Effect analysis
For the effect analysis the list of unit risk (UR) factors compiled by Hofstetter[9] is used. The unit-risk concept (WHO 1987) is used for estimation of the dose response relationship.

The UR factor for inhalation is an estimate of the probability that an average individual will
develop cancer when exposed to a pollution at an ambient concentration of one microgram per
cubic meter for the individual's life (70 years) [UR in cases per $\mu g/m^3$]
UR factors are derived from IRIS(Integrated Risk Information System) (U.S. EPA: Environmental Protection Agency) , WHO Europe and Germany. In case more UR factors are available the most recent factors are preferred.

The Formula used for calculation of the Effect factor for exposure through air is:

$$\text{Effect} = \frac{UR}{70} * PD$$

UR: unit risk(per year) (cases. $\mu g^{-1}.m^3$)
PD: population density (P/m^2)
Effect factor: [cases. $\mu g^{-1}.m^3$ / (m^2. y)]

The Incidence factors in cancer cases per kg emission can be calculated by multiplying the Effect factor with the Fate factor:

$$\text{Incidence (cases/kg)} = \text{Effect factor} * 10^9 * \text{Fate factor}$$

Damage analysis

The estimation of DALYs per incidence case is copied from Hofstetter[9]. For this estimation information on the seriousness of the illness, the duration, the death rate and age of the people affected are used. The total DALYs per kg emission to a specific compartment are calculated by adding the different exposure pathways.

In formula: DALYs per kg emission to air
= Incidence, air-air (cases/kg) * DALYs(inhalation)
+ Incidence, air-drw (cases/kg) * DALYs (oral uptake)
+ Incidence, air- food (cases/kg) * DALYs (oral uptake)

Substance groups of the IARC(International Agency for Research on Cancer) classification are quoted also.

2.2 The damage category Ecosystem Quality

Ecosystems are very complex, and it is very difficult to determine all damages inflicted upon them. An important difference with Human Health is that even if it could, it is not really concerned with the individual organism, plant or animal[13]. The species diversity is used as an indicator for Ecosystem Quality.

Here it is expressed the ecosystem damage as a percentage of species that are threatened or that disappear from a given area during a certain time. In formula, it can be expressed by 3 steps: PDF*area*time(m^2.yr)

Fate analysis: from emission to concentration

Effect analysis: from concentration to hazard unit(HU)

Damage analysis: from HU to damage (PDF/m^2)

Fate analysis

The PDF(Potential Affected Fraction)[14] of species can be calculated for aquatic and terrestrial ecosystems[10]. For aquatic ecosystems the concentration in water is the starting point for the calculation of the damage. For the terrestrial ecosystems the concentration in the pore water of the soil compartment is used. In EUSES[6] four emission compartments air, water, agricultural soil an industrial soil are taken into account. The resulting concentrations in the receiving compartments, water compartment and the pore water of agricultural soil, industrial soil and natural soil, the so-called receiving compartment, determine the damage to ecosystems.

Effect analysis

The toxicity of the substances is characterized by standardized concentrations : HU(Hazard Units). HU is similar to PEC/NEC(the Predicted Environmental Concentration divided by the No Effect Concentration) ratio's. The no-effect concentration is assumed to represent the average NEC for the

whole ecosystem. The values for the average NEC for aquatic and terrestrial ecosystems are derived from a previous study[13].

The HU for an emission of 1 kg are calculated with the following formula:

$$HU\ (air,water) = (E\ (mg.y^{-1})/m^2 * Fate\ factor\ (m^2\ .y)/l\ )\ /\ A\ (mg/l)$$

HU: Hazard Units (dimensionless, standardized concentration)

E = emission

A = Average NEC for all species for a specific substance

Damage analysis

The height of the standardized concentration relates to a certain PDF. The damage depends on the slope of the PDF curve in the workpoint. The workpoint is determined by the present damage.

Each receiving compartment has a specific concentration, resulting from a specific emission. Each

receiving compartment has a specific size[6]. For each compartment the damage is assessed separately. The total damage is the sum of the damages of the separate receiving compartments. The total $PDFm^2$ resulting from an emission of 1 kg is calculated with the following formula:

$$
\begin{aligned}
PDFm^2\ (air) = {} & HU\ (air,water) * dPDF/dHU * \text{Area size water } (m^2) \\
& + HU\ (air,nat.soil) * dPDF/dHU * \text{Area size nat.soil } (m^2) \\
& + HU\ (air,agr.soil) * dPDF/dHU * \text{Area size agr.soil } (m^2) \\
& + HU\ (air,ind.soil) * dPDF/dHU * \text{Area size ind.soil } (m^2)
\end{aligned}
$$

Further details are skipped.

2.3 The damage category Resources

This study only use the model mineral resources and fossil fuels.

In the case of non-renewable resources (minerals and fossil fuels), it is obvious that there is a limit on the human use of these resources, but it is rather arbitrary to give figures on the total quantity per resource existing in the accessible part of the earth crust[4]. If sum up only the known and easily exploitable deposits, the quantities are quite small in comparison to current yearly extractions. If include occurrences of very low concentrations or with very difficult access, the resource figures become huge.
It is difficult to fix convincing boundaries for including or not-including occurrences between the two extremes, as quantity and quality are directly linked[2].

For the damage, a study[3] developed an assessment procedure for the seriousness of resource depletion, based on the energy needed to extract a mineral in relation to the concentration[5]. As more minerals are extracted, the energy requirements for future mining will increase. The damage is the energy needed to extract a kg of a mineral in the future.

For fossil fuels this study also use the concept of surplus energy. Much of the data is quoted from existing study[16].

The unit of the resources damage category is the surplus energy in MJ per kg extracted material, this is the expected increase of extraction energy per kg extracted material, when mankind has extracted an amount that is N times the cumulative extracted materials since the beginning of extraction until 1990. A value of 5 is chosen for N[16]. As the surplus energy is dependent on the choice of N, the absolute value of the surplus energy has no real meaning. Surplus energy is used to add the damages from extracting different resources.

3. Normalization and damage assessment

Normalization

The three damage categories all have different units. In order to use a set of dimensionless weighting factors from the panel it need to make these damage categories dimensionless. The obvious way to do this is to use a normalization step. For the case study, the European normalization values was used [15]. It should be noted that normally in LCA the normalization takes place after characterization, as usually the normalized effect scores are presented to the panel.

Weighting

In the previous paragraph it has shown how to calculate the damage to the three damage categories Human Health, Ecosystem Quality and Resources. In this process we can use the best available scientific knowledge. However, as indicated in the introduction, can not use natural science to determine how serious this damage is perceived.

There are basically two methods to determine values in society:

- Observation of actual behaviour; in this context often referred to as revealed preference method.

The core of this method is to analyse how decisions on comparable issues are taken. For instance in the EPS(Environmental Priority Strategies) method[20] the value of a human life is based on life insurance, and the value of biodiversity is based on governmental expenditure on this issue.

- Questioning representatives of society (a panel: delphi method) on the specific issue.

Mettier[15] performed a carefully conducted panel procedure[1] with a LCA interest group. The procedure contained a ranking and a weighting procedure. The results cannot be considered to be representative for the views of a population, but they generate a useful first default weighting-set. The data was quoted in the case study.

4. Case study

In order to see and testify that the method specified above is workable, a case study has been carried out. This is to assess the environmental load of the substances of the emission list in each process using E-scores calculated according to the methodology studied herewith. The emission list used in the case study is a actual data of environmental inventory analysis from P company who is manufacturing car tires in Korea.

E-scores

The E-scores shown below came as example out of the methodology studied so far, which classified 3 environment categories as damage to human health, damage to ecosystem and damage to resources, and generated the damage factors based on the concept of marginal damage in each category, then calculated with dividing by normalization individual equivalent value per inhabitant and multiplied with the weighting factor of each category.

<Table 4-1> Carcinogenic effects on humans

Compart ment	Substances	E-scores
Air	Arsenic	2.61E+02
Air	Benzene	2.65E-02
Air	Benzo(a)pyrene	4.22E+01
Air	Cadmium	1.43E+03
Air	Chromium (VI)	1.86E+04
Air	Nickel	2.49E+02
Air	PAH's (Polycyclic Aromatic Hydrocarbon	1.80E+00

<Table 4-1> Carcinogenic effects on humans

Water	Arsenic	6.97E+02
Water	Cadmium	7.55E+02
Water	Chromium (VI)	3.64E+03
Water	Nickel	3.30E+02
Water	PAH's	2.76E+01

<Table 4-2> Acidification & Eutrophication

Compart ment	Substances	E-scores
Air	Ammonia	1.21E+00
Air	NO_x	4.45E-01

Emission inventory data (from P tire company)

The datas shown below <Table 4-3> & <Table 4-4> were from production system of P tire company in Korea, which made out for LCA. Among the emissions to air and water, the case study used only the inventory substances that are available of the E-scores calculated.

<Table 4-3> LCA inventory to water in each process

Group	Water Emissions Parameter	Unit	Total Stage	Up Stream	Internal Process	Down Stream
Heavy metals into water	Arsenic (As)	kg	3.958E-06	3.632E-06	3.185E-07	7.285E-09
	Cadmium (Cd)	kg	3.729E-07	1.987E-07	1.585E-07	1.573E-08
	Chromium (Cr)	kg	6.817E-06	5.397E-06	1.310E-06	1.097E-07
	Copper (Cu)	kg	1.629E-06	1.066E-06	5.110E-07	5.214E-08
	Lead (Pb)	kg	1.379E-05	4.719E-06	8.903E-06	1.683E-07
	Nickel (Ni)	kg	7.739E-06	6.200E-06	1.427E-06	1.125E-07
	Zinc (Zn)	kg	3.087E-06	1.749E-06	1.308E-06	2.986E-08
Summzd emissions into air	PAH (polycyclic aromatic hydrocarbons)	kg	1.066E-05	5.866E-06	4.247E-06	5.474E-07

<Table 4-4> LCA inventory to air in each process

Group	Air Emissions Parameter	Unit	Total Stage	Up Stream	Internal Process	Down Stream
Heavy metals into air	Arsenic (As)	Kg	3.222E-06	6.595E-07	2.513E-06	4.955E-08
	Cadmium (Cd)	Kg	2.197E-07	6.631E-08	1.504E-07	2.989E-09
	Chromium (Cr)	Kg	4.785E-06	1.027E-06	3.685E-06	7.292E-08
	Lead (Pb)	kg	1.039E-04	9.429E-05	9.421E-06	1.866E-07
	Nickel (Ni)	kg	3.909E-05	9.887E-06	2.866E-05	5.429E-07
	Zinc (Zn)	kg	3.373E-05	2.662E-05	6.966E-06	1.402E-07
Inorganic emissions into air	Ammonia (NH_3)	kg	1.339E-02	7.716E-05	1.331E-02	2.839E-06
	Sulphurhexafluoride (SF6)	kg	6.000E-13	6.000E-13		
Organic emissions into air	Benzene (C_6H_6)	kg	1.839E-04	1.633E-04	1.556E-05	5.041E-06
	Benzoapyrene ($C_{20}H_{12}$)	kg	2.569E-06	2.460E-06	3.343E-08	7.559E-08
	CFC-11 (CFC-13; Trichlorofluoroethane)	kg	1.318E-04		1.318E-04	
	Formaldehyde (HCHO; methanal)	kg	5.293E-08	5.101E-08	1.742E-09	1.774E-10
	Heptane (C_7H_{16})	kg	1.116E-03		1.116E-03	
	Hexane (C_6H_{14})	kg	1.087E-05		1.087E-05	
	Pentane	kg	5.739E-06		5.739E-06	
	Toluene ($C_6H_5CH_3$)	kg	1.045E-05		1.045E-05	
	Xylene ($C_6H_4(CH_3)_2$)	kg	6.131E-05		6.131E-05	
Standard emissions into air	Carbon dioxide (CO_2)	kg	5.653E+01	3.557E+01	1.923E+01	1.727E+00
	Methane (CH_4)	kg	2.147E-01	1.760E-01	3.675E-02	1.948E-03
	Nitrogen oxides (NO_x)	kg	2.655E-01	1.525E-01	9.567E-02	1.733E-02
	NM VOC (sum parameter) (Non-methane Volatile Organic Compounds)	kg	9.472E-02	5.353E-02	3.458E-02	6.613E-03
Summarized emissions into air	PAH(polycyclic aromatic hydrocarbons)	kg	4.651E-06	1.766E-06	9.762E-08	2.787E-06
	Total Suspended Particular (TSP)	kg	7.166E-05			7.166E-05
	VOC	kg	1.019E-01	1.017E-01	1.657E-04	1.523E-07

The result of Impact assessment

LCA inventory has been applied to the E-scores by multiplying and got the result as following tables <Table 4-5>.

<Table 4-5> Impact ranking of entire emissions

Total Stage	Emission substances	Total scores	Impact ranking (from bigger)
	Carbon dioxide (CO_2)	1.68E-00	1
	Nitrogen oxides (NO_x)	3.67E-01	2
	Chromium (Cr)	1.15E-01	3
	Nickel (Ni)	3.72E-02	4
	Ammonia (NH_3)	2.83E-02	5
	Lead (Pb)	2.06E-02	6
	Methane (CH_4)	1.00E-02	7
	Zinc (Zn)	7.59E-03	8
	CFC-11 (CFC-13; trichlorofluoroethane)	5.52E-03	9
	Arsenic (As)	3.75E-03	10
	NM VOC (sum parameter)	1.29E-03	11
	Cadmium (Cd)	7.75E-04	12
	VOC	6.98E-04	13
	PAH(polycyclic aromatic hydrocarbons)	3.02E-04	14
	Benzoapyrene ($C_{20}H_{12}$)	1.37E-04	15
	Total Suspended Particular (TSP)	8.38E-05	16
	Copper(Cu)	1.87E-05	17
	Heptane (C_7H_{16})	1.32E-05	18
	Benzene (C_6H_6)	5.82E-06	19
	Xylene ($C_6H_4(CH_3)_2$)	1.43E-06	20
	Toluene ($C_6H_5CH_3$)	1.50E-07	21
	Hexane (C_6H_{14})	1.17E-07	22
	Pentane	5.18E-08	23
	Formaldehyde (HCHO; methanal)	6.25E-10	24
	Sulphurhexafluoride (SF_6)	3.37E-11	25

Interpretation

<Table 4-5> shows the assessment result and the ranking of environmental impact. In this assessment, it can be classified with the highest environmental impact substances by substances emitted to air and to water, by each group and by each process.

<table 4-5> can be interpreted such Impact ranking of entire emissions as Carbon dioxide(CO_2) have the highest environmental impact, the second is Nitrogen oxides(NO_x) and the third Chromium (Cr) in order.

Consequently, by reviewing of the forming process and its emission process of these substances in whole production system, it could be possible to find out the priority of environmental improvement at a first glance and could reflect to the actual management for the actual improvement. P Tire company, in order to have more environment friendly management, should decrease the emission of Carbon dioxide(CO_2) in future or should do efforts to replace it with other materials.

5. Conclusion

As specified, LCA is a necessary tool to access the environment performance of a defined system. However, LCIA as an important step of whole LCA is needing tremendous data and many times with the experts.

The methodology is a sub-tool of LCIA to simplify its complicated procedure, which is a damage oriented methodology. This is to calculate the E-scores based on damage influenced to the sound environment, as an index of each environment substance. Once calculated and secured the E-scores, then anybody can apply the E-scores to the quantity of emissions to get the level of environmental impact and could make easily its ranking in environmental load.

Validity

To confirm the validity of this methodology, the emission list from P tire company in Korea was applied. As intended at first, it could check promptly the ranking of environmental load of each substance. The result was almost met with that of normal LCA carried out by P tire company.

Recommendations for further studies

1) Calculation of E-scores on the all environmental substances.
2) Further studies to reduce more the uncertainty.
3) Adding more categories excluded in this study.
4) Studies to reflect the minus damage.

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