LCA Discussions

Weighting Across Safeguard Subjects for LCIA through the Application of Conjoint Analysis

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Abstract

Background. Many types of weighting methods, which have integrated the various environmental impacts that are used for life-cycle impact assessment (LCIA), were proposed with the aim of developing the methodology as a useful information resource for decision making, such as in the selection of products. Economic valuation indexes, in particular, have attracted attention, as their assessment results are easy to understand and can be applied in conjunction with other assessment tools, including life-cycle costing (LCC) and environmental accounting. Conjoint analysis has been widely used in market research, and has recently been applied to research in environmental economics. The method enables us to provide two types of assessment results; an economic valuation and a dimensionless index. This method is therefore expected to contribute greatly to increasing the level of research into weighting methodology, in which an international consensus has yet to be established. Conjoint analysis, however, has not previously been applied to LCIA.

Objective. LCA National Project (METI/NEDO/JEMAI) has conducted a study aimed at the development of a Japanese version of the damage-oriented impact assessment method called LIME (Life-cycle Impact assessment Method based on Endpoint modeling), in order to enhance its reliability and transparency. This study aimed at the application of conjoint analysis to the step of weighting in LIME. An ultimate goal of the research is to determine an amount of willingness to pay (WTP) for avoiding a unit quantity of damage of every safeguard subject (endpoint).

Methods. Potential annual damages of four safeguard subjects (human health, biodiversity, social assets, and primary production), known as normalization values in LCIA, were used as fundamental information in this study. These data can be obtained through damage assessment. Taking this background into account, we performed a comparison of importance among the four safeguard subjects defined in LIME by applying conjoint analysis. A choice-based type of questionnaire was prepared for the interview with the respondents selected by random sampling. Pre-tests were conducted for 108 respondents in advance of the main survey. After we confirmed that the analyzed results of the pre-test were revealed to be statistically significant, the main surveys were conducted for 400 respondents by interviewing. WTP per quota can be determined by statistical simulation based on the random utility theory reflecting the responses to the questionnaires by random sampling.

Results and Discussion. The values of one unit (standard) of attributes were significant statistically at the 1% level (all of the p value for coefficients of safeguard subjects were less than 0.0001). Based on the calculated results, two types of weighting factors, an economic valuation and a dimensionless index were obtained. The capability of generating two kinds of weighting factors is unique to conjoint analysis. A relative comparison of importance among the four categories indicates that human health gains the highest recognition, biodiversity gains the second highest recognition, and the weight of primary production and social assets have been estimated to be relatively smaller than the other two safeguard subjects.

Conclusion. It is desirable to prepare a small number of attributes when conducting a conjoint analysis, because the efforts of respondents have to be reduced as far as possible. We confirmed that the damage-oriented method, which minimizes the number of attributes, is suitable to the requirement of conjoint analysis, because the results of comparisons among safeguard subjects were statistically significant, and showed that the contents of the questionnaires were well understood among the respondents. Judging from the results of this study, where statistical significance has not even been fully verified in the conventional research on the development of weighting coefficients for LCIA, it can be concluded that the weighting factors derived from this study based on the economic theory have a possibility to reveal the impact of environment on society.

Abbreviations: LCIA-Life Cycle Impact Assessment; LIME-Life-cycle Impact Assessment Method based on Endpoint modeling; CVM-Contingent Valuation Method; WTP-Willingness to Pay; DALY-Disability Adjusted Life Year, EINES-Expected Increase in Number of Extinct Species, NPP-Net Primary Production, PRTR-Pollutant Release and Transfer Register

Keywords: Biodiversity; conjoint analysis; damage assessment; LCA National Project; life cycle impact assessment; LIME (Life-cycle Impact assessment Method based on Endpoint modeling); safeguard subjects; weighting

1 Background and Objectives

Since life-cycle assessment (LCA) was first recognized as a useful tool for establishing environmental management, many impact-assessment methods have been proposed. Product-design departments of manufacturing companies require that information on the environmental impact of their products be simple and explicit, because they have to consider many aspects of product performance. From this point of view, there is an intense interest in the weighting method, among the various steps of Life Cycle Impact Assessment (LCIA).

Various environmental impacts, including global warming, ozone-layer depletion, air pollution, and resources depletion can be expressed in a single index by using a weighting method. The types of endpoint, such as human and ecosystem, and the mechanisms of the environmental impacts vary widely depending on the environmental problems. The results of weighting, taken as indexes of environmental impacts, are therefore divided into (1) dimensionless indexes, individually set by method developers (for example, Goedkoop 1999, Itsubo et al. 2000a), or (2) monetary expressions of environmental impacts converted into economic terms (for example, EC 1998, Steen 1999). The former have been proposed from a comparatively early stage of the development of weighting methods, as they have the flexibility to reflect the ideas of method developers in relation to environmental impacts on a definition of a single index. In the former, however, the meaning of each index differs from method to method so that the assessment results cannot be directly compared. In the latter, on the other hand, although there are some questions regarding the reliability of the results of the economic assessment method, differences among results can be easily discussed as they are expressed as monetary values. Moreover, because the results obtained are so-called external costs that society has to bear, the economic assessment method has the merit of superior usability, in that the results obtained can be compared with life-cycle costs, and applied to environmental accounting. Currently, no international consensus has been reached on which index should be used.

In the economic valuation method, environmental impacts are calculated as damage amounts by (1) calculating the damage of endpoints caused by the occurrences of environmental loading, and (2) multiplying predetermined economic values per unit endpoint by the results obtained in (1). For the values of endpoints used in (2), the results obtained by the contingent valuation method (CVM) could be applied.

We used conjoint analysis as an economic valuation method; this method has recently attracted attention in its application to environmental economics. Conjoint analysis enables the description of values of various attributes as economic indexes, on the condition that a partial effect of one of the attributes is described in terms of monetary value like tax, through the assessment of utilities of pre-defined attributes. Although it should be possible to develop weighting factors based on the conjoint analysis by handling the endpoints as attributes, such investigations are not currently conducted in the field of LCIA. CVM economically evaluates the overall utility of the assessment objects, whereas conjoint analysis economically evaluates assessment objects after a weighting is carried out for partial utilities of them. International standard ISO 14042 (2000) describes a guideline for a general procedure of LCIA and specifies the last stage of the LCIA as weighting. For the ISO framework on weighting, which requires taking into account the importance of a number of components, it can be said that the conjoint analysis, which reflects the weighting results among endpoints on a single index, is closer to the idea of ISO for weighting than the approach of CVM, which eventually gives a single index by independently evaluating the environmental values of each endpoint. Conjoint analysis, furthermore, has the merit that it can be used to calculate both a dimensionless index and an economic valuation index at the same time.

Taking this background into account, the aim of the present study was to acquire information relating to the development of single indexes by conducting an economic valuation of the unit damage of each endpoint, by applying the conjoint analysis as an economic valuation tool in LCA.

2 LIME (Life-cycle Impact Assessment Method based on Endpoint Modeling) and the Scope of this Research

The Ministry of Economy, Trade and Industry has funded a national project of life cycle assessment (henceforth called LCA Project), with a five-year plan starting in 1998, which ended in March 2003, and which aims to develop a database that will allow industries to easily conduct a highly reliable LCA (JEMAI 2003). LCA Project includes studies aimed at developing a Japanese version of the life cycle impact assessment method. The method was developed for quantifying environmental impacts that are induced by the occurrence of environmental loading in Japan, as accurately as possible and with a high degree of transparency. The ultimate aim of the project was to publish three lists: characterization, damage assessment, and weighting.

Characterization, one of the mandatory steps of LCIA, produces an indicator for each impact category, such as global warming and ozone-layer depletion; these results therefore have a high reliability, because assessments can be conducted based on the knowledge of natural science. The result of characterization, however, might not directly lead us to decision-making (including product selection), as the possibility to meet trade-off relationships, owing to the large number of impact categories, is comparatively higher. On the other hand, although the weighting method has the merit of giving a single index, it inevitably involves value judgments among endpoints, as in the case of comparison between human health and the ecosystem.

Damage assessment has a limited number of safeguard subjects compared with that of impact categories, because indexes can be aggregated into endpoints such as human health and biodiversity; the uncertainty of the calculated result of damage assessment, however, might be higher than that of characterization, because more models and parameters need be introduced. In addition, because damage assessment can avoid the value judgment among the endpoints that are involved in the step of weighting, it is more reliable than weighting, but cannot provide a single index. As mentioned above,

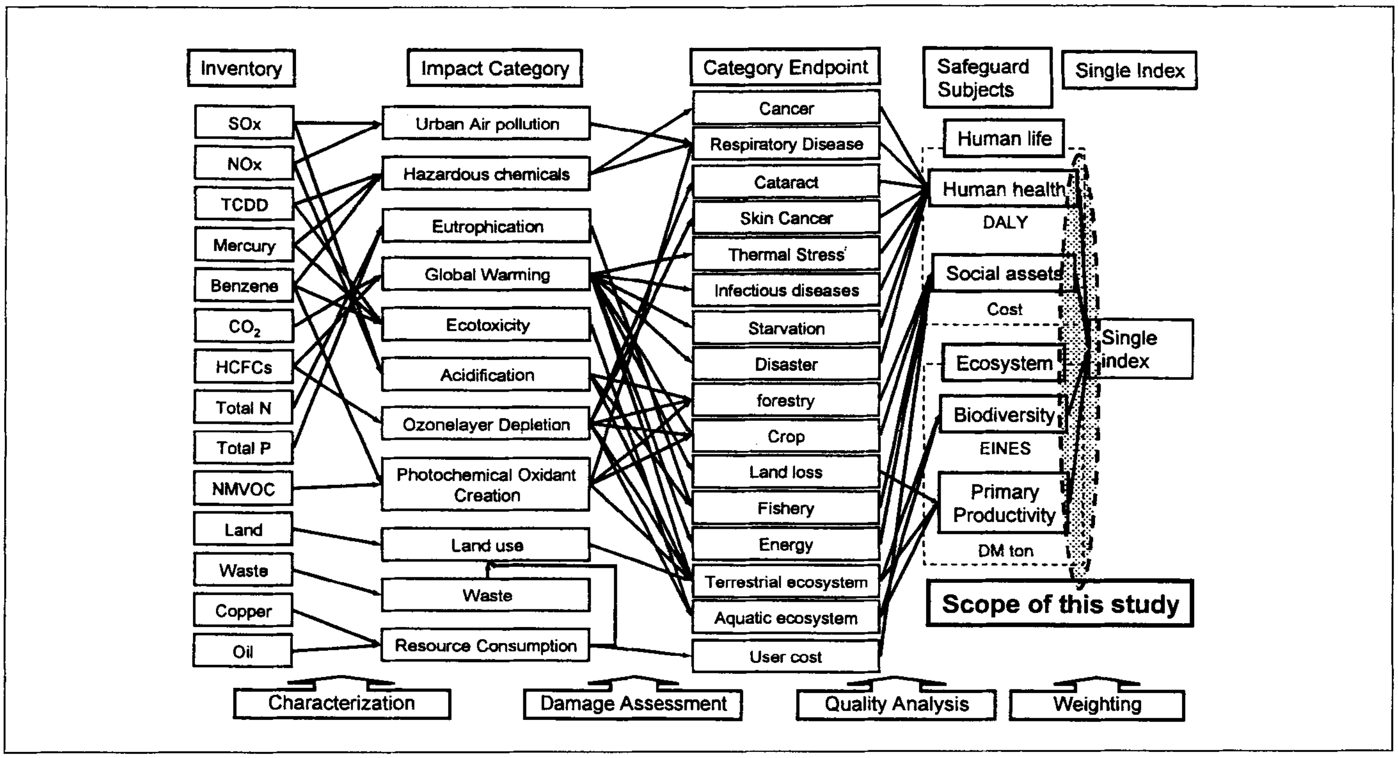

Fig. 1: Conceptual figure of LIME (Life-cycle Impact assessment Method based on Endpoint modeling) and the scope of this study

each step of LCIA has different characteristics. The choice of which method to use is desirable for practitioners and should be based on their goals of LCA.

LIME (Life-cycle Impact assessment Method based on Endpoint modeling), developed in the LCA project, published three lists (characterization, damage assessment, weighting) to meet various objectives of LCA as widely as possible. **Fig. 1** shows the framework and the scope of this method. Knowledge obtained from this paper is utilized in the weighting across the importance of safeguard subjects and the calculation of weighting factor for each substance in LIME.

3 Approach Employed in this Research

3.1 Outline of conjoint analysis

The following discussions are mainly based on the works of Washida (1999) and Kuriyama (2000).

Conjoint analysis is a measurement method that was established by the psychologist Luce and others in the 1960s, and has since been developed in marketing research as a tool for measuring consumer preference. It is used to reduce risks in advance of new product launches and market developments by the prediction of profitability and market share to be obtained by conducting questionnaire surveys. Comprehensive researches on the utilization of conjoint analysis in the marketing field have been conducted by Louviere and Woodworth (1983), Green and Srinivasan (1990), Cattin and Wittink (1982), and Goldberg, Green, and Wind (1982).

According to Washida (1999), conjoint analysis is a generic name for the methods of assessing individuals' preferences for each of a number of attributes. Conjoint analysis generally uses cards called profiles that bind every attribute. The profiles specify products composed of multiple attributes. An automobile, for example, has various attributes, such as the engine capacity, number of passengers, maximum speed, price and shape of body. Each profile is generated by specifying attributes and their levels for the object, such as a 1500-cc engine capacity, five passengers, a maximum speed of 200 km/hr, price JPY 1.5 million and a sedan body. Worth (called 'utility' in the field of economics) per attribute can be obtained by showing such profiles to respondents and asking them for their preferences among the profiles. The biggest difference between conjoint analysis and CVM is that the former can measure value in detail for each of the attributes (partial utility), whereas the latter evaluates an object or event as a whole (whole utility). Therefore, it is appropriate to apply the conjoint analysis to measure the importance of the component of environment like biodiversity and human health.

Questionnaires conducted in conjoint analysis can be classified into three types; a full-profile evaluation type, a pair-wise evaluation type, and a choice-based type. With respect to the full-profile evaluation type and the pair-wise evaluation type, according to Kuriyama (1999), questionnaires where preset purchase probabilities or rearranged profiles, and partial profiles containing only a part of the presented attributes do not conform with the actual consumption behaviors and are therefore unrealistic (Green et al. 1991). The choice-based conjoint is a highly realistic questionnaire format, because it very closely represents daily consumption behaviors; choosing the most preferred option among a number of merchandises. It is known, from a psychological

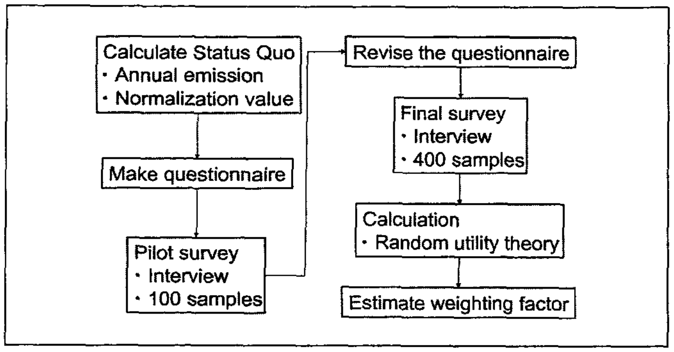

Fig. 2: Procedure to evaluate weighting factors of safeguard subjects applying conjoint analysis

point of view, that humans cannot handle more than six items of information simultaneously (Miller 1956), so the number of attributes listed in the profile should be minimized. The number of attributes adopted in this study was five items in total: four safeguard subjects defined in LIME and one tax. This, therefore, is within the allowable range for the use of the choice-based conjoint.

Based on the factors discussed above, we evaluated utilities for each safeguard subject, based on the choice-based conjoint analysis. The survey flow of this study is outlined in **Fig. 2**.

An ultimate goal of the research is to determine an amount of willingness to pay (WTP) for avoiding a unit quantity of damage of every safeguard subject (endpoint). WTP per quota can be determined by statistical simulation reflecting the responses to the questionnaires by random sampling.

3.2 Estimation Model

Conjoint analysis makes estimations by the conditional logit model, based on random utility theory. The following discussions are based on studies by McFadden (1974), and by Ben-Akiva and Lerman (1985).

In the random utility theory, it is assumed that utilities vary at random, and a utility function involving a definite term V and a random term e is given by:

$$U_i = V_i (x_i, t_i) + e_i \tag{1}$$

where x_i is an attribute vector of a profile i, and t_i is a monetary attribute. The probability of a respondent choosing a profile i, namely, a probability P_i for $U_i > U_j$ at a given moment, is:

$$\begin{aligned} P_i &= Prob\ (V_i + e_i > V_j + e_j) \\ &= Prob\ (e_i - e_j > V_j - V_i) \end{aligned} \tag{2}$$

When the first extreme value distribution is assumed to be a probability distribution of the error term, the probability is expressed by:

$$P_i = \frac{exp(V_i)}{\Sigma exp(V_j)} \tag{3}$$

This is the conditional logit model. The scale parameter is normalized to one. Parameters are estimated by the maximum likelihood method.

Following on from this, an amount of marginal willingness to pay (MWTP), a welfare measure, is derived. First, the following utility function is considered where β is the parameter to be estimated.

$$V = \Sigma\ \beta_i x_i + \beta_t t \tag{4}$$

A total differentiation of the above gives:

$$dV = \Sigma \frac{\partial V}{\partial x_i} dx_i + \frac{\partial V}{\partial t} dt \tag{5}$$

When the utility level does not change ($dV = 0$), and attributes other than the said attribute are invariable, the following is obtained

$$MWTP = \frac{dt}{dx_i} = -\frac{\beta_i}{\beta_t} \tag{6}$$

4 Preparation of Questionnaires for Conjoint Analysis

4.1 Definitions of safeguard subjects and damage indicators

At first, profile design should be conducted to prepare the questionnaires used in the conjoint analysis. As a prerequisite for this task, we need to identify the attributes that constitute the profiles. Since weighting in this study is conducted across safeguard subjects, these are defined as the attributes that constitute the profiles. The Impact Assessment Study Committee of LCA Project has been discussed to determine safeguard subjects from the point of view of environmental ethics and has, consequently, defined four items – human health, social asset, primary production and biodiversity – as safeguard subjects (Itsubo 2000b). The first two items are classified as components representing human lives, and the last two items are classified as components for ecosystem preservation. When conducting weighting, attention needs be paid to reducing the number of safeguard subjects as far as possible in order to reduce the efforts of choice for the respondent. Also, the definition of damage indicator that quantity the damage per safeguard subject is essential to perform conjoint analysis. Any further decrease in the numbers of the above four items seems extremely difficult for developing reasonable damage indicators.

Next, damage indicators representing the amounts of damage to the safeguard subjects were defined. The development of damage functions that relate LCI data with the amounts of damage incurred by safeguard subjects has been discussed in the Impact Assessment Study Committee of LCA Project. As shown in **Table 1**, DALY (Disability Adjusted Life Year), EINES (Expected Increase in Number of Extinct Species), NPP (Net Primary Production) and Loss of monetary value (Yen) were adopted as damage indicators in LIME.

Table 1: Damage indicators adopted in LIME

Safeguard subject	Damage indicator	Dimension
Human health	DALY	Year
Social assets	Social cost	Japanese Yen
Biodiversity	EINES	Extinct number of specie
Primary production	NPP	Dry-ton

DALY is an index developed by Murray, with the cooperation of the World Bank and the World Health Organization (WHO), to quantify the total amount of worldwide health losses (Global Burden of Disease: GBD) caused by deaths and diseases (Murray et al. 1996). DALY is the sum of the years of life lost due to premature mortality and the years lived with disability. Results of GBD research have appeared in the World Health Report, published every year by WHO, and have contributed greatly, in that they have been reflected in the medical policies of various nations. DALY has already been utilized by Hofstetter (1998) and by Goedkoop (1999) in the field of LCIA. DALY has a time dimension, and is usually expressed in years.

Regarding the damage indicator for biodiversity, the extinction of species are taken into account. EINES can be obtained by summing the number of species existing in Japan multiplied by the incremental risk of extinction of the species. The increase in the risk of extinction of species are measured based on the knowledge from conservation biology. The impacts caused by the exposure of toxic substances and that caused by land transformation including landfill of waste and extraction of resources were also taken into account.

NPP is equivalent to a balance of a Gross Primary Productivity which subtracted the amount consumed by plant respiration. NPP varies with the physiological and ecological characteristics of the plants, the climatic conditions, and the soil conditions. As a result, the NPP of an ecosystem varies with the climatic zone on the globe that it occupies, from values close to zero in deserts and tundra, to approximately 30-ton dry matters/ha/year in tropical rain forests. Research on NPP began in the 1970s, and has generated ample results until now. Lieth et al. (1975) obtained NPP by vegetation area and by water area, and made a topographic presentation of the worldwide NPP distribution. Seino et al. (1985) mapped the distributions of NPP in Japan, and evaluated the net nationwide production by Japan.

4.2 Setting of a scenario

In the conjoint analysis used in this research, a profile design was made by combining pieces of information on the safeguard subjects. Then, the meanings of the profiles needed to be explained to respondents in understandable terms, so that they could make decisions reflecting their own value judgments correctly. We presented the profiles as options for national environmental policies.

4.3 Calculation of normalization values

As we described above, in preparing questionnaires for conjoint analysis, it is important to present quantitative information related to each attribute. The choice-based conjoint used in this study can present a profile showing the current environmental status quo, as well as setting a profile as an alternative in which specific attributes are changed from the status quo. It was therefore necessary to calculate the profile for the status quo.

Calculated results of the amounts of damage to the safeguard subject caused by the occurrence of environmental loading in Japan were used in this research as the profile representing the status quo. In general, the amount of impact during a certain period in a particular region is named the normalization value in LCIA. The step of normalization is an optional element in ISO standard, and involves non-dimensionalizing all impact categories under a certain common standard, by dividing the results for characterization per impact category by the normalization value (ISO 2000). Normalization is often used as a pre-treatment for weighting.

Normalization values for each safeguard subject were determined in order to allow weighting across the safeguard subjects shown in Table 1. Calculation of the normalization values is conducted by summing products of annual environmental loading amounts and damage factors which express the potential damage of safeguard subject per unit environmental loading.

$$\text{Normalization Value}_e = \sum_s \left(\text{Annual Environmental Loading}_s \times \text{Damage Factors}_{s,e}\right) \quad (7)$$

Normalization Value$_e$:	an annual amount of damage incurred by the safeguard subject e.
Annual Environmental Loading$_s$:	the annual amount of environmental loading (kg) of environmental loading substance s in Japan.
Damage factor$_{s,e}$:	a damage factor (damage/kg) of environmental loading substance s for safeguard subject e.

Damage functions developed by Impact Assessment Study Committee of LCA Project were used to obtain damage factors. Damage function is a calculated amount of damage incurred by safeguard subject through a specific impact process caused by a unit of the discharge of environmental loading substances. An example of damage function is the loss of life expectancy due to the occurrence of malaria caused by discharging one unit of carbon dioxide. Because the damage functions are calculated for each process of environmental impact, a sum of the damage functions is equivalent to the damage factor.

$$\text{Damage Factors}_{s,e} = \sum_t \text{Damage Function}_{s,e,t} \quad (8)$$

Damage Function$_{s,e,t}$: a damage amount (damage amount/kg) incurred by a safeguard subject e through a specific process of environmental impact t caused by the loading of one unit of an environmental loading substance s.

Table 2: Substances and category endpoints considered in the calculation of normalization values for each safeguard subject

Safeguard subject	Impact category	Safeguard subject and Category endpoint	Substance
Human health	Global warming	thermal stress, cold stress, malaria, dengue fever, disaster, food shortage	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6
	Ozonelayer depletion	skin cancer, cataract	CFCs, Halons, CCl4, 111-TCE, HCFCs, HBFCs, CH_3Br
	Photochemical ozone creation	acute death, respiratory disease, asthma attack	NMVOCs, NO_x, CO
	Urban air pollution	respiratory disease	CO, SO_2, NO_x
	Chemical substances	respiratory disease, cancer	Arsenic, Benzene, Cadmium, Chromium(VI), Nickel, 2.3.7.8-TCDD, 1.1.2-TCE, CH3Cl, tri-chloroethylene, di-chloroethylene, 1.1.2-trichloroethane, chloromethane, trichloroethylene, dichloromethane, 1.2-dichloroethane, 1.1- dichloroethane, cyanogens compounds, lead, copper, 1.1.1-TCE
Biodiversity	Ecotoxicity	aquatic species	Arsenic, Benzene, Cadmium, Chromium(VI), Nickel, 2.3.7.8-TCDD, 1.1.2-TCE, CH3Cl, tri-chloroethylene, di-chloroethylene, 1.1.2-trichloroethane, chloromethane, trichloroethylene, dichloromethane, 1.2-dichloroethane, 1.1- dichloroethane, cyanogens compounds, lead, copper, 1.1.1-TCE, tetrachloroethylene, 1.3-dichloropropene, thiuram, simazine, thiobencarb, selenium, fluorine, boron
	Land use	vascular plant species	road construction, develop river, develop marsh and pond, develop coast, develop grassland, land preparation, construct dam
	Resource consumption	vascular plant species	aluminum, chromium, copper, iron, lead, manganese, mercury, molybdenum, nickel, tungsten, tin, gold, silver, uranium, vanadium, antimony, titanium, niobium, coal, oil, natural gas, limestone, rock
	Waste	vascular plant species	waste
Primary production	Global warming	terrestrial plant	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6
	Ozone layer depletion	forest, phytoplankton	CFCs, Halons, CCl_4, 111-TCE, HCFCs, HBFCs, CH_3Br
	Acidification	terrestrial plant	NO_x, SO_2, NH_3, HCl
	Land use	terrestrial plant	Paddy field, upland field, orchard, forest, land for building, land for trafic
	Resource consumption	terrestrial plant	aluminum, chromium, copper, iron, lead, manganese, mercury, molybdenum, nickel, tungsten, tin, gold, silver, uranium, vanadium, antimony, titanium, niobium, coal, oil, natural gas, limestone, rock
	Waste	terrestrial plant	waste
Social assets	Global warming	crop, energy	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6
	Ozone layer depletion	crop	CFCs, Halons, CCl_4, 111-TCE, HCFCs, HBFCs, CH_3Br
	Eutrophication	fishery	COD, total phosphate, total nitrogen
	Photochemical ozone creation	crop, forest	NMVOCs, NO_x, CO
	Resource consumption	User cost	aluminum, chromium, copper, iron, lead, manganese, mercury, molybdenum, nickel, tungsten, tin, gold, silver, uranium, vanadium, antimony, titanium, niobium, coal, oil, natural gas, limestone, rock

Data on annual emission of substances and annual consumption of resources were obtained. Annual domestic discharged amounts were quoted when they were available in the literature. In the case of substances for which data were unavailable in the literature, particularly chemical substances, the annual amounts discharged domestically in Japan were estimated from results of the pilot survey of the Pollutant Release and Transfer Register (PRTR) (Ministry of the Environment 2002). **Table 2** summarizes the substances and category endpoints involved to calculate the normalization value.

Normalization values were calculated for each safeguard subject based on the above information. The results are given in **Table 3.** These results were utilized as basic data when we explain about the current status of environmental impact. In the environmental economic valuations using CVM, photographs and illustrations are frequently used to promote the understanding of questionnaires by respondents. However, photographs (such as natural scenes) cannot show in the case of safeguard subjects. To promote the respondents' understanding, we tried to get them to obtain a quick grasp of the status quo by attaching graphs to explanations of the attributes. Interviewing was introduced into the survey method by having the investigators explain the whole scheme by reading an explanation sheet directly to each respondent.

Table 3: Result of normalization values for safeguard subjects

Safeguard subject	Human health	Social assets	Primary production	Biodiversity
Unit	**DALY**	**1million JY**	**Dry-ton**	**EINES**
Global warming	9.49E+4	1.20E+6		
Ozonelayer depletion	5.68E+3	3.32E+1	4.52E+5	
Acidification		3.02E+5	1.83E+6	
Eutrophication		2.28E+4		
Photochemical oxidant creation	1.56E+4	5.22E+4		
Urban air pollution	3.83E+5			
Chemical substances	4.38E+4			
Ecotoxicity				5.00E-2
Land use			7.00E+7	2.00E-1
Resource consumption		7.14E+5	1.20E+8	6.66E-1
Waste			1.70E+6	7.30E-3
Normalization value	**5.43E+5**	**2.29E+6**	**1.94E+8**	**9.23E-1**

4.4 Setting of attributes and their levels

Levels of the attributes presented in the questionnaire were set based on the results of the normalization values as standards. As mentioned before, the normalization values obtained correspond to the profiles representing the status quo of the attributes. Four levels were set here for each safeguard subject: the normalization value as a standard, one-half and one-quarter of the relevant impact amounts, and a zero-damage amount. An item related to expenditures for environmental preservation was added as a monetary attribute in order to provide a situation which is close to real society. There are two kinds of applicable expenditure forms as a monetary attribute, tax and fund. A rise in taxes applied only for the year it was adopted, since the damage information on the safeguard subject is also provided in terms of one year.

The profile design was made by an orthogonal design for 4^5 combinations of the attributes, and their levels. **Table 4** shows an example of the questionnaire. The right-most is the current profile that is derived from the normalization value. In the actual questionnaire, the most desirable profile is to be selected among three options by each respondent. The questionnaire formats in Table 4 were presented eight times to each respondent.

With regard to the human health attribute, a calculation result, related to health impact, was obtained so that one year's discharge of environmental-loading substances was seen to induce an annual health damage amounting to 5.4×10^5 years. Fukuda (1999) calculated that all annual health damage amounts in Japan amount to 1.3×10^7 years. If we assume the current calculation results are limited only to domestic health impacts, health loss as an environmental impact comprises approximately 4% of the whole. Immediate application of normalization values for the setting of levels was considered to be extremely difficult for respondents to understand. Therefore, in order to make it more easily understandable, the normalization values were divided by the population, and we obtained years of lost life per capita (approximately 1 day/person), which was used as a standard value representing the impact amounts in the status quo. Furthermore, by considering the possibility that the days of life lost per year is still not sufficiently understandable in terms of the degree of damage, a piece of information was offered to aid respondents' understanding, such as the days of life lost per year is equivalent to about a 2-month loss if this situation were to continue for 50 years.

Table 4: A sample of profile used in questionnaire

Attribute	Option 1	Option 2	Status Quo
Human health	0.5 day of life expectancy (1 month in 50 years)	No loss of life expectancy (0 day)	Keep present status (2 months in 50 years)
Social assets	No loss	Keep present status (loss of 1.5 million JY in 50 years)	Keep present status (loss of 1.5 million JY in 50 years)
Primary production	Decrease to a quarter of the loss of plant productivity (3.75 billion ton in 50 years)	Decrease to the half of the loss of plant productivity (7.5 billion ton in 50 years)	Keep present status (loss of 15 billion ton in 50 years)
Biodiversity	Extinction of 0.1 species additionally (5 species in 50 years)	No extinction	Keep present status (extinction of 50 species in 50 years)
Additional tax Per 1 year, per 1 household	10 thousands JY added annually	5 thousands JY added annually	No extra payment

5 Main Survey and the Results

The main surveys were conducted by interviewing in the manner described in Table 5, by using the questionnaires including the above-described profiles.[1]

Table 6 shows the results of a statistical calculation of respondents' results obtained in the above manner based on the random utility theory described in Section 3.2.

Coefficients in Table 7 mean the value of one unit (standard) of each attribute. The larger the absolute value of coefficient revealed, the higher people regard it as important. All coefficients were significant statistically at the 1% level (all of the p value for coefficients of safeguard subjects were less than 0.0001), and their sign condition were consistent (negative). The presence of a bias towards the status quo bias was not verified at a statistically significant level. We calculated the weighting factor ($WF_{1,e}$), which is expressed as a monetary value per unit damage for the safeguard subject from these results. The calculation was made for 46,607,000 households and 127,291,000 persons.

By utilizing the weighting factors (the amount of willingness to pay for a unit of damage to safeguard subject) in the above, weighting in LCIA can be conducted as shown below, and the result can be expressed as a monetary amount. Since the results of LCI are environmental loadings discharged by subject products during their life cycles, the integrated result calculated by the following equation corresponds to a cost that society must pay.

$$I_1 = \sum_e \sum_s (\text{Inv.}_s \times \text{Damage Factor}_{s,e} \times \text{Weighting Factor}_{1,e}) \qquad (9)$$

where

I_1: a result of weighting in LCIA based on the economic valuation (Japanese yen)

Inv._s: a result of Life Cycle Inventory of a substance s (kg)

$\text{Weighting Factor}_{1,e}$: an amount of monetary value for one unit of damage to a safeguard subject (yen/unit damage amount)

[1] Pre-tests were conducted in advance of the main survey for 108 respondents, with the same survey subjects, method, and regions. The results are reflected in the preparation of the main survey questionnaires.

Table 7: The amount of monetary value, Weighting Factor1,e obtained from the result of the conjoint analysis

Safeguard subject	Unit	Weighting Factor$_{1,e}$ (JY/a unit)
Human health	1 DALY	9.70E+6
Social assets	10,000 JY	1.00E+4
Primary production	1 ton	2.02E+4
Biodiversity	1 specie loss	4.80E+12

Table 8: The result of the relative weighting factor based on an annual amount of damage to a safeguard subject

Safeguard subject	WTP for annual damage	Weighting factor$_{2,e}$
Human health	5.27E+12	0.31
Social assets	3.61E+12	0.21
Primary production	3.91E+12	0.23
Biodiversity	4.43E+12	0.26

From the viewpoint of weighting across safeguard subjects by the same standard, total damage amounts of money for the annual damage amounts were calculated by using the results described in Table 7. New weighting factors were obtained from these results. They can be calculated by multiplying $WF_{1,e}$, obtained in Table 7, by the normalization values (Table 3). The results are shown in Table 8.

Since the weighting factors given in Table 8 are for annual amounts of damage to the safeguard subjects, the integration of LCIA can be made by multiplying the weighting factors by the damage assessment results divided by the normalization values.

$$I_2 = \sum_e \sum_s \left(\frac{\text{Inv.}_s \times \text{Damage Factor}_{s,e}}{\text{Normalization Value}_e} \times \text{Weighting Factor}_{2,e} \right) \qquad (10)$$

where

I_2: an integration result of LCIA obtained using a Weighting Factor $_{2,e}$ (dimensionless)

$\text{Weighting Factor}_{2,e}$: a weighting factor in terms of an annual damage amount of a safeguard subject e (dimensionless)

Table 5: Summary of the investigation

Male/Female	Twenties	Thirties	Forties	Fifties	Total
Male	43	43	31	37	**154**
Female	42	43	31	36	**152**
Total	85	86	62	73	**306**

Respondents: Male and female from 20 to 50 ages – Procedures: Interview – Place: Tokyo – Period: 22th to 25th January 2002 – The number of samples: 306 – Period of age and distinction of sex

Table 6: The calculated result of conjoint analysis

Attribute	Coefficients	Standard	Standard error	t value	p value
Human health	−0.645	Day/person/household	0.068	−9.504	<0.0001
Social assets	−0.243	10000JY/person/household	0.024	−10.157	<0.0001
Primary production	−0.385	1.0E+8ton/household	0.032	−11.973	<0.0001
Biodiversity	−0.915	1 specie loss/household	0.071	−13.005	<0.0001
Tax	−5.77E-5	1 JY/household	3.91E-6	−14.733	<0.0001

The number of samples: 306; ρ^2=0.12; probable logarithm: −2380.51

The capability of generating two kinds of weighting factor is unique to the conjoint analysis. The annual damage amounts were different among the safeguard subjects, but were of the same order of magnitude. From the above results, a relative comparison of importance among the four categories indicates that human health gains the highest recognition, biodiversity gains the second highest recognition, and the weight of primary production and social assets have been estimated to be relatively smaller than the other two safeguard subjects.

The current research represents the first example of a weighting across the four safeguard objects defined in the LCA Project. Eco-indicator' 99 (Goedkoop 1999), a damage calculation-type LCIA, conducted a relative comparison among three items (human health, ecosystem quality, and resources) by panel method. It employed cultural theory, and classified the items into three patterns – hierarchist, egalitarian, and individualist perspectives – and evaluated their weighting factors. The weighting factors for human health, ecosystem quality, and resources were 4:4:2 for the hierarchist perspective, 3:5:2 for the egalitarian perspective, and 5.5:2.5:2 for the individualist perspective, respectively.

Because the evaluation of the ecosystem quality in Eco-indicator' 99 is the aspect that uses ratios of disappeared species as an index, the biodiversity is the closest match among the targets of the current research. Social assets, one of the safeguard subjects of this study, include mineral resources, fossil fuels, biomass, living aquatic resources, and farm crops. Eco-indicator' 99 focuses on mineral resources and fossil fuels in its Resource item, so that this item can be regarded as a subset of the safeguard subject social assets in LIME. For health impact, the subject ranges of both research methods are equivalent. We will compare both sets of results, taking into consideration these differences in their subject ranges.

The four safeguard subjects set in LIME were obtained first by classifying each of the subjects into two categories of human lives and ecosystem, and then by dividing them further into two items from a qualitative and quantitative point of view (**Table 9**). When the weighing of these results is carried out in terms of its being a broader term, the ratio of human lives to ecosystem is seen to be approximately 0.5:0.5 from sums of the components.

The resources defined as one of the safeguard subjects in Eco-indicator 99 are fossil fuels and mineral resources. It can be seen that the values for these resources are generated from their utilization in human society; therefore, they are regarded as being closely related to human lives. By applying the comparison in such broad terms as seen in Eco-indicator 99, weighting factors for human lives and ecosystem are 6:4 for the hierarchistic perspective, 5:5 for the egalitarian perspective, and 7.5:2.5 for the individualistic perspective. This indicates that the results of this study are close to the result for the egalitarian and hierarchistic perspective of the Eco-indicator 99.

Table 9: A list of safeguard subject defined in LIME

First level of safeguard subject	Human lives	Ecosystem
Qualitative point of view	Human health	Biodiversity
Quantitative point of view	Social assets	Primary production

6 Conclusions

A damage-oriented impact-assessment method, LIME was developed by AIST in cooperation with the Impact Assessment Study Committee of LCA Project, and aims at reflecting the conduct of impact assessments of three steps: characterization, damage assessment, and weighting. In weighting, the final process, a single index description is obtained by applying the weighting factors of the safeguard subjects to the damage amounts of the safeguard objects, presented as results of the damage assessments. This research aims at an investigation for highly convincing weighting of the safeguard subjects. We examined the conjoint analysis as a feasible method for the calculation of the following two types of weighting factor:

(1) An amount of monetary value for avoiding a unit amount of damage to a safeguard subject.
(2) A relative weighting coefficient based on an annual amount of damage to a safeguard subject.

The former weighting enables the calculation of the social expenditures, whereas the latter allows an LCA to be conducted, as specified by ISO 14042 (2000), by the sequence of characterization, normalization, and weighting. The significance of applying the conjoint analysis to LCIA is that both types of weighting factor can be obtained based on economic theories.

It is desirable to have a small number of attributes when conducting a conjoint analysis, because the efforts of respondents have to be reduced as far as possible. The problem comparison-type method, which is conventionally used as an integration method for the LCIA, is regarded as being unsuitable for multi-attribute assessments, as more than ten environmental problems need to be compared at the same time. We employed the damage-oriented method, which enables the calculation of damage amounts to endpoints for each safeguard subject, and minimizes the number of attributes. Although multi-attribute assessments of environmental topics by the conjoint analysis are widely conducted in environmental economics, this study is believed to be the first that systematically applies the conjoint analysis to the LCIA method.

In conventional research on evaluation, such as humankind and ecosystem in environmental economic valuation, information on the damage conditions of endpoints, which should be provided as fundamental information for discussing their importance, has been qualitative. Even when the information is either qualitative or quantitative, expressions have often been used that describe the phase before the occurrence of actual damage, such as the atmospheric concentrations of pollutants. Damage-assessment results based on the damage function, as used in our research, describe the amounts of damage to endpoints as attributes, quantitatively and in specially selected units. Little research applying the quantitative damage-assessment results to profile designs has been conducted in the field of environmental assessment.

The results of comparisons among safeguard subjects, while reflecting research results of the damage function, were statistically significant, and showed that the questionnaires were well understood among the respondents. Judging from the current situation, where statistical significance has not even been fully verified in the conventional research on the development of weighting coefficients for LCIA, we can say that we obtained results that could be used in the weighting of LCIA.

The current results indicate that human health is regarded as the most important factor, biodiversity the second most important factor, and primary production and social assets are regarded as having equal importance. The results in this research represent expected values obtained based on the various levels of environmental consciousness of individuals in the group of respondents. Eco-indicator 99 breaks down the environmental consensus possessed by individuals into three categories, and then sets weighting factors for each. Since the results of the current research had a high statistical significance, categorization was deemed to be of low necessity. However, calculation of weighting factors for categorized items is useful from a viewpoint to reflect investigators' environmental consensus in the weighting as much as possible, and to conduct comparisons among weighting methods. The necessity for the categorization of the environmental consciousness should be verified in the future.

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Current Status of Weighting Methodologies in Japan

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In Japan, requirements for the development of valuation methodology are very stringent. Several methodologies have been proposed to meet these demands in recent years. These methods, however, are quite different in many points such as selected impact categories, the numbers of substances considered, and basic concepts for the environment. The results of LCA are fully dependent on the goals of LCA practitioners and commissioners. If they misunderstand the concept of method and use it, the result may not fit for the purpose. Consequently, it is important to characterize the methods selected by the practitioner in accordance with their LCA goals.

In this paper, weighting methodologies proposed in Japan have been introduced with a comparison between the results of case studies for common industrial products. Furthermore, we considered the present situations and future directions of valuation methodologies in Japan. This consideration is carried out based on the results of investigations performed by the Impact Assessment Committee of the National LCA Project of Japan.