DEVELOPMENT OF GLOBAL SCALE LCIA METHOD

Development of weighting factors for G20 countries—explore the difference in environmental awareness between developed and emerging countries

Norihiro Itsubo[1] · Kayo Murakami[2] · Koichi Kuriyama[2] · Kentaro Yoshida[3] · Koji Tokimatsu[4] · Atsushi Inaba[5]

Abstract

Purpose Weighting is one of the steps involved in LCIA. This enables us to integrate various environmental impacts and facilitates the interpretation of environmental information. Many different weighting methodologies have already been proposed, and the results of many case studies with a single index have been published. LIME2 (Itsubo et al. Int J Life Cycle Assess 17(4):488-498, 2012) developed weighting factors for four different areas of protection that reflect environmental awareness among the Japanese public. This method has already been widely used in Japan, but difficulties exist universally using the Japanese weighting factors around the world. It is presumed that the weighting varies depending on economic, cultural, and social conditions, and there are still few cases in which weighting factors have been specifically invented or studied in consideration of variance in these elements. This study attempted to develop weighting factors applicable to the Group of Twenty (G20) countries with a view toward developing those that could be used in different countries. In the study, a survey was conducted with a uniform questionnaire in G20 countries to compare the weighting factors calculated for different countries, along with an investi-gation on development and utilization of global weighting factors.

Methods A conjoint analysis was conducted to give a weighting between the four areas of protection defined by LIME: human health, social assets, biodiversity, and primary production. The analysis is suitable for measuring the value of each of the multiple attributes of the environment. This study conducted a questionnaire in all the G20 member states. The survey puts priority on making the questions understood by the respondents and minimizing bias, adopting interviews, visiting surveys, and surveys in venues in the 11 emerging countries. In the developed countries, Internet surveys were conducted after confirming that their results are statistically significant from the pretest results in these states. In both sur-veys, random sampling was performed to take 200–250 sam-ples (households) in each of the emerging countries and 500–600 samples in each of the developed countries. The surveys collected a total of 6400 responses. Statistical values based on this model can be considered to reflect the variability between each individual's environmental thoughts. The calculated re-sults can then be used to compare the variety of environmental thoughts in developed and emerging countries.

Results and discussion The study was able to obtain two dif-ferent kinds of results: dimensionless weighting factors and economic indicators using the amount of willingness to pay. This paper solely presents the former. The weighting factors in the entire G20 community, in the group of developed coun-tries (G8) and in the group of emerging countries (G20 states excluding the G8) and those in the individual G20 countries, were estimated. The calculated values were significant statis-tically at the 1 % level (all *p* values for the safeguard subject coefficients were less than 0.0001), with the exception of monetary attributes for several emerging countries. Converted into dimensionless values, so that the total sum for the four subjects equals 1, the weighting factor was the

✉ Norihiro Itsubo
  itsubo-n@tcu.ac.jp

[1] Tokyo City University, Yokohama, Japan

[2] Kyoto University, Kyoto, Japan

[3] Nagasaki University, Nagasaki, Japan

[4] Tokyo Institute of Technology, Tokyo, Japan

[5] Kogakuin University, Tokyo, Japan

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highest for human health in the entire G20 circles, at 0.34, followed by biodiversity at 0.29, and primary production at 0.23. The weighting for social assets was relatively poor, at 0.13. In the G8 developed states, the figures of biodiversity and primary production were relatively higher than those of the same two subjects in the full G20. Biodiversity had the highest value, at 0.34, and was followed by human health at 0.30. On the other hand, in emerging countries, the weighting of health impacts was particularly significant, at 0.44, whereas the three other subjects had almost equivalent weightings—biodiversity at 0.19, social assets at 0.18, and primary product at 0.18. The weighting factors by country and the variance of preference intensities by country showed minor differences among developed countries while they reflected considerable differences among emerging countries.

Conclusions Accurate weighting factors representing the environmental attitudes of the world and national public are needed in order to conduct general purpose LCA. This study is the world's first to conduct surveys with the use of the same questionnaire not only in developed countries but also in emerging countries, and to compare the findings. A total of 6400 responses were obtained via interviews and Internet surveys. The survey thus gained a statistically significant result on all the environmental attributes including the weighting factors for the G20 circles, G8 states, emerging countries exclusive of the G8 states, and individual countries in which surveys took place. The results have revealed a relatively minor difference in weighting factors and variation coefficients between the areas of protection in the developed countries whereas a considerable difference was observed between those subjects in emerging countries.

Abbreviations

DALY Disability adjusted life year
EINES Expected increase in number of extinct species
LCIA Life cycle impact assessment
LIME Lifecycle impact assessment method based on endpoint modeling
NPP Net primary production

1 Introduction

Weighting is the process of converting indicator results of different impact categories by using numerical factors based on value choices. In environmental systems analysis tools like life cycle assessment, results need to be presented in a comprehensible way to make alternatives easily comparable. One way of doing this is to aggregate results to a manageable set by using weighting methods. Weighting is defined as one of the steps involved in LCIA (ISO 14040 2006; ISO 14044 2006), and a variety of approaches have been developed to date.

During the 1990s, a number of methods were proposed to determine the weights used to compare different impact categories such as global warming and acidification (Müller-Wenk 1994; Goedkoop 1995; Hauschild and Wenzel 1997; Yasui 1998; Itsubo 2000). Methods to determine the weights to be given to endpoints (damage-oriented approach) such as human health and biodiversity have also attracted attention because they impose less burden on the respondents—requiring fewer endpoint categories (5 or less) than impact categories (which can require 10 items or more). Various methods such as Eco-indicator 99 (Goedkoop and Spriensma 1999), EPS (Steen 1999), and LIME (Itsubo et al. 2004, 2012) have proposed weighting factors (the economic value or weighting value of one unit of the damage sustained by the areas of protection) based on damage-oriented approach. These methods can be broadly classified into either the panel method or the economic evaluation method.

Using the panel method, experts and general consumers evaluate environmental impacts by means of questionnaires or group discussions. Eco-indicator 99 derives weighting factors from the weighting given by LCA experts, based on a comparison of three predefined areas of protection (human health, ecosystem quality, and resources). One characteristic of this method is that it classifies the weights in terms of different ways of thinking about the environment (hierarchist, egalitarian, and individualist). However, sample size is not always enough to ensure representativeness of the survey results.

Recently, several methods of economic evaluation have also been published in the scientific literature increasing the credibility and the review process. Examples of more recent methods are methods based on monetary valuation of endpoints (Itsubo et al. 2004; Weidema 2009), the Ecotax method based on a monetary valuation of midpoints (Finnveden et al. 2006), and panel methods for midpoints (Soares et al. 2006; Huppes et al. 2007). Pizzol et al. (Pizzol et al. 2014) reviewed existing economic assessment methods and concluded that the choice experiment method and the budget constraint method are the best options for monetary valuation in LCA.

As seen above, numerous weighting factors have been developed and already used in different countries. However, the existing ones are all designed for specific countries or regions. In principle, the weighting factors obtained by conducting a questionnaire or other survey in a particular country cannot be used in assessment of any other country. This means that the conventional weighting factors have yet to reach the level at which they can be broadly used around the world. The

following outlines the challenges concerning the weighting factors to be sorted out:

1. Develop weighting factors that represent the environmental awareness in a country or region. No studies have presented common environmental data to multiple countries and regions and made international comparison of weighting results in different countries based on their responses.
2. Explore the difference in environmental awareness between developed and emerging countries. The past developments and studies of weighting factors were mainly for developed countries, and there have been few studies covering emerging countries. There has been no study examining whether there is any difference in environmental awareness between developed and emerging countries, or any difference among developed countries and among emerging countries.
3. Develop weighting factors that represent the entire world. No studies have aimed at developing weighting factors with a highly representativeness that can be used around the world by comparing the findings on weighting factors for all developed, emerging, and individual countries.

2 Purpose of the study

Itsubo et al. (2012) applied the technique of conjoint analysis, which has been the focus of much attention in the fields of market research and environmental economics (Green et al. 1991), for the purpose of weighting in LCIA, and developed statistically significant weighting factors. A statistical analysis of responses from 1000 respondents randomly sampled from all over Japan produced statistically significant results in all four environmental attributes: human health, social assets, biodiversity, and primary production. The weighting factors representing Japanese environmental awareness can be generally used in life cycle assessments (LCAs) on Japan, but cannot be directly used in assessments on other countries.

This study therefore conducted the following in efforts to develop weighting factors that can be used all over the world:

1. Development of weighting factors for major separate countries. This study worked to develop weighting factors for individual nations reflecting their environmental awareness. In consideration of the geographical balance, it focused on the G20 member states. It used a uniform questionnaire in the surveys so that the factors for different countries could be compared.
2. Comparison between developed and developing countries. The study defined the group of developed countries (G8) and emerging countries (G20 countries excluding

the G8 states) to calculate weighting factors for each group to make a comparison. It also made comparison among developed countries and among emerging countries to examine whether environmental awareness differed within the group.
3. Development of weighting factors representing the entire world. The study attempted to calculate weighting factors representing the entire world. By comparing the outcome with the weighting factors for different groups (i.e., developed and emerging countries) and for different countries (e.g., the USA and Canada), it assessed if the resulting weighting factors really represented the entire world and discussed if they could be used in the LCA.

This study adopts the conjoint analysis used in LIME. With use of this method, it obtains two different types of weighting factors. One type, hereinafter WF1, pertains to the results of relative weighting among the four areas of protection—human health, social assets, biodiversity, and primary production—determined in advance. The other group, hereinafter WF2, concerns the result of obtaining the amount of willingness to pay for averting damage per unit quantity. This paper presents the results of calculating WF1 alone. The study also performed an analysis in the random parameter logit model to obtain the statistic values of weighing factors to explore their mean value as well as their dispersion.

The following describes the characteristics of the results obtained from this study:

1. The weighting factors for the individual G20 member states are obtained and compared.
2. The weighing factors that represent the entire world or specific entire regions are obtained as are those for the developed and emerging countries.
3. The statistical values of the weighting factors are obtained to reveal their dispersion.

3 Study methods

3.1 Subjects of assessment

This study followed the LIME framework and defined the four areas of protection—human health, social assets, biodiversity, and primary production—as subjects of evaluation. Figure 1 portrays the relationships between them. Human health and social assets were considered to be constituents of human society, which serves as a higher-level concept, while biodiversity and primary production constitute a higher-level concept of ecosystem. Human health and biodiversity were defined as elements representing the quality of human society and the ecosystem, while social assets and primary production
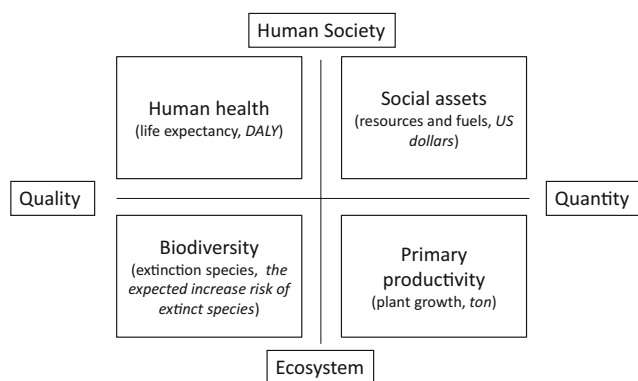
Fig. 1 Relationship of four types of areas of protection. The elements of each areas of protection and the unit of damage indicator (written in *italic face*) are shown in *parenthesis*

are elements representing quantity of their respective upper level concepts. The elements of each endpoint and damage indicators were also described in the figure. We selected disability adjusted life years (DALY), expected increase in number of extinct species (EINES), net primary productivity (NPP), and monetary loss for the damage indicators of human health, biodiversity, primary production, and social assets, respectively. The definition of areas of protection and damage indicators were followed by the structure of LIME2 (Itsubo et al. 2010).

3.2 Research flow

Figure 2 is a flowchart showing how the survey was carried out. This involved six main processes:

1. Selection of countries and cities to be surveyed: This study prioritized countries that represented particular continents or regions and defined the G20 member states, composed of eight countries forming the Group of Eight (G8) and 11 other emerging countries, as survey subjects. It was desirable to conduct random sampling that covers each whole country to be surveyed, but the study, in consideration of survey efficiency, selected the city with the largest economic scale in each of the countries surveyed.
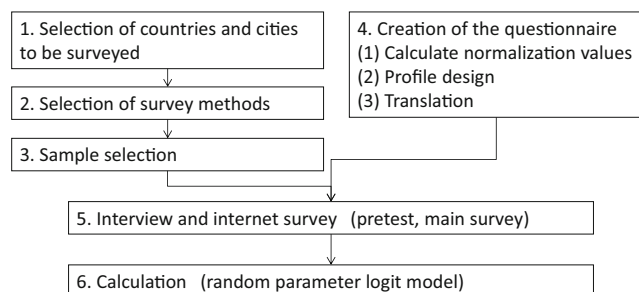2. Selection of survey methods: Possible survey methods include interviews, telephone survey, Internet survey,

Fig. 2 Research flow of this study

and many others. Among these, interviewing is considered the most appropriate for minimizing bias (NOAA 1993). It is also time- and labor-consuming and has difficulty in securing a sufficient number of samples under budgetary constraints. This study determined to basically conduct interviews while adopting Internet surveys where they were confirmed to produce results comparable with interviews in efforts to place priority on conducting surveys in all G20 member states.

3. Sample selection: Sample households were selected for the survey at random. For many of the countries where interviews were conducted, this study used a two-stage random sampling method in which the locations were selected first, before selecting the samples (households). Specific households were then selected at each location. We collected approximately 200–600 samples for each country considering the balance of age and income to keep the representativeness of each country.
4. Creation of the questionnaire: We created a questionnaire to be used for the interview and Internet survey. In this study, the term "questionnaire" refers to a sheet which contained questions and all the information that the respondents needed to know before answering the questions, including a description of various environmental attributes, the profile of attributes used for the conjoint analysis, and questions about the respondents' attributes. The questionnaire used for the conjoint analysis provided quantitative information for each attribute described in the various survey profiles.
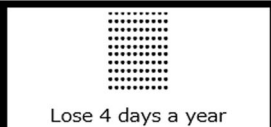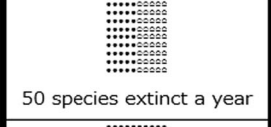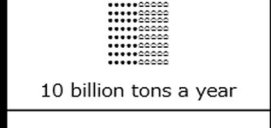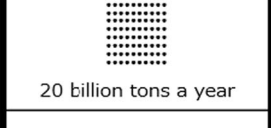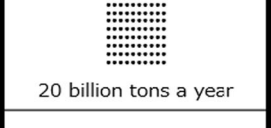
Table 1 shows an example of the profiles used. Respondents were asked to choose from the three policies. Policies 1 and 2 are the profiles adjusted for hypothetical situations including environmental improvements and the additional payment of environmental tax. The profile used for the current situation is shown in policy 3. This study used the calculation results derived from a set of reference values to represent the current profile.

Table 2 shows these reference values used in this study. Reference values in LIME include four kinds of areas of protection such as human health (loss of life expectancy), social assets (loss of valuables in human society such as fishery, agriculture, and forestry), biodiversity (extinction of species), and primary productivity (plant growth inhibition). Reference values (RV) can be obtained from the multiplication annual environmental burdens (AEV) for each substance (X) and country (C) by endpoint type characterization factor (CF) in each impact category (impact) and country (C).

$$RV = \sum_{\text{Impact}} \sum_{C} \sum_{X} \left(AEV_{X,C} \times CF_{X,C,\text{Impact}} \right) \quad (1)$$

The profile of the current situation shown here was included in all questionnaires so that the respondents could always

Table 1 An example of the profiles used in this study

		Plan A	Plan B	No action (Plan C)
L O S S	Loss of health per person	Lose 4 days a year	No loss of life	Lose 4 days a year
	Loss of natural resources per person	Lose 15US$ a year	No loss of resources	Lose 60US$ a year
	Loss of species	100 species extinct a year	50 species extinct a year	100 species extinct a year
	Loss of forests	10 billion tons a year	20 billion tons a year	20 billion tons a year
T A X	Addnl. TAX (yearly per household)	Additional 100US$ yearly	Additional 200US$ yearly	No additional expenditure

We used dotted format in the profile in order to facilitate understanding the changes of environmental impacts in each environmental attribute

compare and contrast the current and hypothetical situations. We added a monetary attribute (environmental tax) in the profile. This is expected to support respondents to imagine the situation that takes place in a daily life. The questionnaire was translated into the national languages of the individual countries surveyed. The monetary attributes and the value of social assets were converted into the currency of the country surveyed with the use of the World Bank's purchasing power parity (World Bank 2014).

Table 2 Reference values indicating the current situation of environmental impacts

	Human health	Social assets	Biodiversity	Plant production
Unit	DALY(years)	Million US$	EINES (species)	Billion ton
GW	2.1E + 7	−4.6E + 4	3.4E+1	-
AP	3.4E + 7	-	-	-
PO	1.9E + 6	-	-	-
WU	2.2E +7	-	-	-
LU	-	-	5.2E+1	1.3E+1
FF	-	2.9E + 5	3.2E-1	1.5E-1
MR	-	1.6E + 5	4.5E-2	2.6E+0
BR	-	-	1.6E+1	4.6E+0
Total	7.9E + 7	4.0E + 5	1.0E+2	1.8E+1

GW global warming, *AP* air pollution, *PO* photochemical ozone creation, *WU* water use, *LU* land use, *FF* fossil fuel consumption, *MR* mineral resource consumption, *BR* biotic resource consumption

5. Interview and Internet survey: In the case of face to face survey, researchers who were familiar with the contents of the questionnaire visited each respondent's house and explained the questionnaire in detail before obtaining the answers. In Internet surveys, respondents gave their replies to the questionnaire provided in HTML format online.

6. Calculation: The results collected from the respondents were statistically analyzed to derive the weighting factors. This study used the random parameter logit model (RPL) to measure statistic values as well as representative values. As the details of calculation procedures are written in Itsubo et al. (2012), the main part of calculation procedures was explained in the next clause.

It was extremely important to ensure that the responses were not based on any misunderstanding by the respondent since, unlike products such as cars and electric appliances, the environmental attributes being evaluated could be difficult for the respondents to conceptualize. Before conducting the main survey, we conducted pretest several times to verify whether the contents of the survey had been adequately explained and to confirm that each respondent understood what was required. The main survey was conducted after confirming from the pretest results that the questions in the questionnaire were fully understood. Table 3 shows the process and outline of pretests and main survey. Because the

Table 3 The process and outline of pretests and main survey

	Pretest (1st)	Pretest (2nd)	Pretest (3rd)	Main survey
Aim	>To consider the possibility of economic assessment in global scale >Trial of investigations in developing countries	>To consider the credibility of web survey for developed countries >To compare the results of web survey and face to face survey	>Trial of survey for G20 countries >Comparison among the calculated results of G20 countries	>To establish weighting factors of G20 countries
Survey period	From Jan/2012 to Feb/2012	From Nov/2012 to Dec/2012	June 2013	From Aug 2013 to Sep 2013
Countries surveyed and procedure	5 countries (Japan, South Africa, Kenia, Viet Nam)	4 countries (USA (web), Japan (web, CLT), India (RW) China (CLT)	G20 countries G8 (web), G20 countries excluding G8 (CLT, RW, street intercept)	G20 countries G8 (web), G20 countries excluding G8 (CLT, RW, street intercept)
The number of samples	50 (CLT, RW)	50 (CLT, RW)、100 (Web)	50 (web, CLT, RW, street intercept)	500 – 600 (web), 200 (CLT, RW, street intercept)

CLT central location test, *RW* random walking test

results of Viet Nam and Kenia were not significant statistically, we concentrated on the survey for G20 countries in the main survey.

3.3 Calculation procedure

The results collected from the respondents were statistically analyzed to derive the weighting factors. The study used the random parameter logit model (RPL). The conditional logit (CL) model (McFadden 1974) used by Itsubo et al. (2004) is an analytical model widely used in environmental economics. The conditional logit model is 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 the following:

$$\mathrm{Ui} = \mathrm{Vi}\,(\mathrm{xi}, \mathrm{ti}) + \mathrm{ei} \tag{2}$$

where xi is an attribute vector of a profile i, and ti is a monetary attribute. The probability of a respondent choosing a profile i, namely, a probability Pi for Ui > Uj at a given moment, is as follows:

$$\mathrm{Pi} = \mathrm{Prob}\,(\mathrm{Vi} + \mathrm{ei} > \mathrm{Vj} + \mathrm{ej})$$
$$= \mathrm{Prob}\,(\mathrm{ei}{-}\mathrm{ej} > \mathrm{Vj}{-}\mathrm{Vi}) \tag{3}$$

When the type I extreme value distribution (Gumbel distribution) is assumed to be a probability distribution of the error term, the probability is expressed by the following:

$$P_i = \frac{\exp(V_i)}{\sum \exp(V_j)} \tag{4}$$

Parameters are estimated by the maximum likelihood method.

First, the following utility function is considered where β is the parameter of preference intensity to be estimated.

$$V = \sum \beta_i x_i + \beta_t t \tag{5}$$

The above formula can be also expressed as follows in this study.

$$V = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_t t \tag{6}$$

where the numbers from 1 to 4 are environmental attributes in this study: human health, social assets, plant productivity, and biodiversity, respectively.

A total differentiation of the above gives the following:

$$\mathrm{d}V = \sum \frac{\partial V}{\partial x_i} dx_i + \frac{\partial V}{\partial t} dt \tag{7}$$

When the utility level does not change (dV=0), and attributes other than the said attribute are invariable, the preference intensity β can be obtained. The random parameter logit model assumes stochastic variation in the preference intensity. This is expressed by integration using the usual logit probability, Pji, and the density function of a given distribution, f(β):

$$P_{ji}{}^{*} = \int P_{ji}(\beta) f(\beta|\varTheta) d\beta \tag{8}$$

where Pji* is the probability that the individual, i, chooses the option j

Θ: the parameter of the probability density function of β (i.e., means and dispersions)

$$P_{ji} = \frac{\exp(V_{ji})}{\sum_{k} \exp(V_{ki})} \tag{9}$$

The random parameter logit model assumes a continuous distribution, such as a normal distribution, for f(β). The selection probability is formulated as simulated probability (SP), as shown below:

$$SP_{ji} = \frac{1}{R} \sum_r P_{ji}(\beta^r) \tag{10}$$

R: the number of selections, βr: the r-th random selection from the density function.

This is used to estimate the log likelihood function (SLL), and the parameter Θ which defines the distribution that maximizes this function (Train 2003).

$$SLL = \sum_i \sum_j d_{ji} \ln(SP_{ji}) \tag{11}$$

where dji is a dummy variable which is set at 1 when the individual, i, chooses the option, j. The distribution function which quantifies the variability in preference intensity found between different individuals can be derived from these calculations.

The calculation results correspond to the change of utility to a unit of damage. With the use of the results, dimensionless weighting factors normalized to ensure that the total sum of the values for the four areas of protection would be 1.

4 Results

4.1 Results of calculation of weighting factors

Table 4 shows the results of calculation of preference intensity concerning environmental attributes in the full Group of Twenty (G20; consisting of 19 countries excluding the European Union), Group of Eight (G8; eight countries), and group of G20 countries excluding the G8 states (11 countries), and in each of the G20 countries. The results suggest, for example, that the USA sees a loss of utility by 0.68 against curtailment of life expectancy of all humans on the planet by 1 day in a year. The fact that all these values are negative means that the utility against the growth of damage has declined. In all the attributes for the G20, G8, and non-G8 countries in the G20, the results were statistically significant at the level of 1 %, though part of the results were invalid. For Saudi Arabia, the likelihood ratio index (LRI) was as extraordinary high as over 0.9. It is speculated that a strong bias worked at the time of responding to the survey and considered that might be inappropriate as a weighting factor representing particular countries.

The figures in Table 4 may allow comparison between different attributes. Table 5 and Figure 3 show the results, or weighting factors, normalized to ensure that

the total sum of 1 after multiplying the aforementioned results by the reference value.

$$WF(Safe, c) = \frac{\beta(Safe, c) \times RV(Safe)}{\sum_{Safe}(\beta(Safe, c) \times RV(Safe))} \tag{13}$$

Hence, a weighting factor of 0.25 or more means that it is above the average among the four subjects.

In the full G20, human health had the highest weighting factor, at 0.34, followed by biodiversity at 0.29, and primary production at 0.23. Social assets had a smaller weighting, at 0.13, than the three other subjects. In the G8 developed countries, biodiversity had the highest weighting factor at 0.34, followed by health impacts (0.30), and primary production (0.26). The weighting of social assets, at 0.10, was less than half that of biodiversity. Meanwhile, in the emerging countries, the weighting of human health was particularly high, at 0.44, with a share of over 40 %. The three other subjects had nearly equivalent weight factors, ranging from 0.18 to 0.19.

In around 70 % of the countries surveyed, human health had the highest weighting factor. Among others, in all the emerging countries except Russia, the weighting of human health was remarkably high—at 0.51 in Saudi Arabia, 0.49 in South Africa, 0.47 in Indonesia, 0.46 in Brazil, and 0.44 in Argentina. In many countries including these, the weighting factor for it surpassed 0.4. Regarding the developed countries, nearly half, including the USA, Canada, and Italy, saw human health given the highest weight but put poorer weighting on health impacts than emerging countries. In particular, the weighting factor of human health stood at 0.18 in Germany and 0.21 in Japan. In these two countries, it was lower than average (0.25) and less than half the weighting factor of human health in emerging countries mentioned above. In emerging countries, health impacts of environmental pollution with PM 2.5 particles and water use are getting more serious. Meanwhile, in many developed countries, average life expectancy reached 80 years, and the health impacts of pollution are controlled to some extent. This gap may reflect the difference in relative significance of human health between emerging and developed countries.

Social assets had weighting factors below 0.2 in all developed countries. The figure was even below 0.15 in many countries, such as USA at 0.06, Italy at 0.11, France and Australia at 0.13. In contrast, their weighting factors are greater than 0.2 in many emerging countries, including Argentina at 0.30, Mexico and Turkey at 0.23. As a whole, the figures show that they are more weighted in emerging countries than in developed countries. Irrespective of the scale of the reserve of mineral resources or fossil fuels, developed countries may put less weight on social assets than emerging countries,

Table 4 The results of calculation of preference intensity (β(Safe, c)) concerning environmental attributes in the full Group of Twenty (G20; consisting of 19 countries excluding the European Union), Group of Eight (G8; eight countries) and group of G20 countries excluding the G8 states (11 countries), and in each of the G20 countries

		Number of sample	LRI	Preference intensity			
				Human health	Social assets	Biodiversity	Primary production
G20		6183	0.47	-6.3E-01	-1.7E-02	-2.1E-02	-9.8E-03
G8		4507	0.45	-5.5E-01	-1.3E-02	-2.5E-02	-1.1E-02
G20 excluding G8		2037	0.46	-8.7E-01	-2.6E-02	-1.5E-02	-8.7E-03
Country specific	United States	483	0.47	-6.8E-01	-7.1E-03	-2.1E-02	-9.9E-03
	Canada	543	0.47	-6.7E-01	-2.3E-02	-2.2E-02	-1.1E-02
	Australia	484	0.45	-4.7E-01	-1.7E-02	-2.7E-02	-1.0E-02
	Germany	509	0.46	-3.3E-01	-1.8E-02	-2.8E-02	-1.3E-02
	United Kingdom	515	0.50	-6.4E-01	-2.4E-02	-2.6E-02	-1.2E-02
	France	508	0.43	-5.1E-01	-1.7E-02	-2.2E-02	-1.1E-02
	Japan	591	0.46	-3.9E-01	-2.1E-02	-2.5E-02	-1.3E-02
	Italy	513	0.50	-7.0E-01	-1.5E-02	-2.4E-02	-1.1E-02
	Korea	184	0.42	-4.9E-01	-1.9E-02	-1.4E-02	-8.9E-03
	Argentina	195	0.66	-1.1E+00	-5.1E-02	-1.2E-02	-7.5E-03
	Saudi Arabia	200	*0.92*	*-4.5E+00*	*-7.9E-02*	*-6.6E-02*	*-3.6E-02*
	Russia	177	0.40	-4.0E-01	-1.8E-02	-1.6E-02	-7.0E-03
	Mexico	167	0.49	-5.6E-01	-2.9E-02	-1.5E-02	-8.4E-03
	Turkey	191	0.51	-7.5E-01	-3.5E-02	-2.2E-02	-9.1E-03
	Brazil	182	0.39	-6.1E-01	-1.5E-02	-1.0E-02	-5.8E-03
	South Africa	179	0.46	-8.1E-01	-2.0E-02	-1.2E-02	-6.3E-03
	China	199	0.53	-4.1E-01	-1.9E-02	-1.3E-02	-5.8E-03
	Indonesia	176	0.54	-6.3E-01	-1.6E-02	-6.9E-03	-7.2E-03
	India	187	0.68	-9.0E-01	-3.3E-02	-1.9E-02	-1.0E-02

Likelihood ratio index (LRI) is analogous to the R-square in the linear regression model suggested by McFadden (1973). McFadden's likelihood ratio index is bounded by 0 and 1. For Saudi Arabia, weighting factor should be utilized as reference because of extraordinary high value of LRI. It is speculated that a higher bias might work at the time of responding to the survey

possibly because developed countries with relatively strong economic power would think that resources could be imported and recycled.

Moving to biodiversity, a high weighting factor, exceeding 0.3, was given in a majority of the developed countries, for example, 0.38 in Germany, 0.37 in Australia, and 0.33 in Japan. In contrast, a weighting factor of 0.2 or below was given in almost half of the emerging countries: for instance, 0.13 in Argentina and Indonesia. A huge dissimilarity was observed between developed and emerging countries. In developed countries, the government takes the initiative in research and editing the Red Data Book, sharing of information on extinction and preservation of species, and may use of such information in environmental education. This is thought to explain the difference.

Regarding primary production, the weighing factor stood at 0.23–0.31 in all developed countries. Among them, it was generally lower than that of biodiversity. Among the emerging countries, the weighting factor was generally lower, ranging 0.14–0.26, than among the developed countries. In emerging and other developing countries, foresting areas are on the decline due to development and other activities while they are instead increasing in developed countries due to tree planting (FAO 2006). This shows that developed countries may have relatively high awareness of the importance of primary production. Afforestation, greening activities, and other forest preservation activities are in fact vigorously implemented in developed countries.

4.2 Tendency of weighting factors by country

Figure 4 shows a scatter diagram with gross domestic product (GDP) per capita on the horizontal axis and weighting factors by country on the vertical axis. Dots representing emerging countries are seen on the left-hand side and those representing developed countries on the right-hand side. The diagram also includes regression lines summarizing the relationship between four areas of protection and GDP per capita. It is observed that weighting of all areas of protection is in close correlation with GDP per capita. The two subjects concerned

Table 5 The results of weighting factors normalized to ensure the total sum of 1

|		Human health	Social assets	Biodiversity	Primary production
G20 (WF_{G20})		0.34	0.13	0.29	0.23
G8 (WF_{G8})		0.30	0.10	0.34	0.26
G20 excluding G8 (WF_{G20excG8})		0.44	0.18	0.19	0.19
Country specific	United States (WF_{USA})	0.39	0.06	0.30	0.25
	Canada (WF_{CAN})	0.33	0.16	0.27	0.23
	Australia (WF_{AUS})	0.26	0.13	0.37	0.25
	Germany (WF_{DEU})	0.18	0.14	0.38	0.30
	United Kingdom (WF_{GBR})	0.30	0.15	0.30	0.25
	France (WF_{FRA})	0.29	0.13	0.32	0.27
	Japan (WF_{JPN})	0.21	0.16	0.33	0.31
	Italy (WF_{ITA})	0.35	0.11	0.30	0.24
	Korea (WF_{KOR})	0.33	0.18	0.23	0.26
	Argentina (WF_{ARG})	0.44	0.30	0.13	0.14
	Saudi Arabia (WF_{SAU})	*0.51*	*0.13*	*0.19*	*0.18*
	Russia (WF_{RUS})	0.30	0.19	0.29	0.22
	Mexico (WF_{MEX})	0.33	0.23	0.22	0.21
	Turkey (WF_{TUR})	0.34	0.23	0.25	0.18
	Brazil (WF_{BRA})	0.46	0.16	0.19	0.19
	South Africa (WF_{ZAF})	0.49	0.17	0.18	0.17
	China (WF_{CHN})	0.32	0.21	0.27	0.20
	Indonesia (WF_{IDN})	0.47	0.17	0.13	0.23
	India (WF_{IND})	0.40	0.21	0.21	0.19

For Saudi Arabia, weighting factor should be utilized as reference because of extraordinary high value of LRI. It is speculated that a higher bias might work at the time of responding to the survey

with human society—health impacts and social assets—are more heavily weighted where GDP per capita is smaller. In this case, the regression line is negatively sloped. The two subjects concerned with the ecosystem—biodiversity and primary production—are more heavily weighted where GDP per capital is larger. In this case, the regression line is positively sloped.

In comparing human health and social assets, it was found that the absolute value of the inclination of the regression line for human health (-4E-6) was slightly larger than that for

Fig. 3 The comparison of weighting factors normalized to ensure the total sum of 1
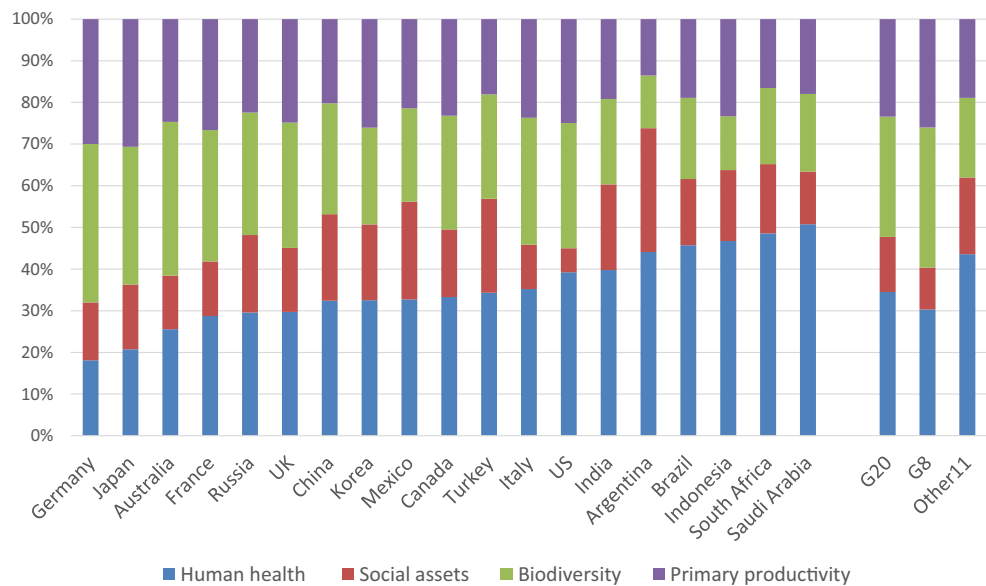
social assets (-3E-6). This suggests that higher priority is given to human health as a qualitative element of human society in emerging countries. In many emerging countries, average life expectancy is around 70 years, for example, 52.8 in South Africa and 68.8 in Russia. On the other hand, in all the developed countries, average life expectancy is over 80 years: for instance, 83.4 in Japan and 81.9 in Australia and Italy. There is a difference of nearly 10 years between emerging and developed countries. Health impacts of water and air pollution are also higher in emerging countries than in developed countries, which suggests that health impacts following environmental changes are perceived as a more immediate issue in emerging countries, and it is thought that people there are more strongly motivated to improve their health status to a level equivalent to that of developed countries. Under the modern market economy conditions, countries with high GDP and greater economic power have greater advantage in access to resources. With lower GDP levels but higher GDP growth rates than those of developed countries, emerging nations are considered to be highly motivated to bolster their economic scale to a level equivalent to those of developed countries. It is speculated that this difference in real conditions is behind the high weighting factors of human health and social assets in emerging countries and the low weighting factors of these subjects in developed countries.

For the two subjects pertaining to the ecosystem—biodiversity and primary production—the weighting factors were higher where GDP per capital was larger. Many developed countries are located in temperate and subarctic zones while many emerging countries are at low latitudes and in tropical and subtropical zones. With the exception of Saudi Arabia and some other countries, emerging countries are richer in biodiversity and primary production capacity than developed countries. In addition, in many areas of developed countries, land use change and development already took place, and a considerable number of species have already been lost. In many such countries, the government takes the initiative in activities aimed at protecting rare species. In emerging countries, human health is particularly prioritized, and a relatively low level of priority is given to the ecosystem. The circumstances described above are thought to be behind higher weighting factors of the subjects related to the ecosystem in developed countries than in emerging countries.

In comparing biodiversity and primary production, it was found that the inclination of the regression line for biodiversity (4E-6) was larger than that for primary production (2E-6). Developed countries see their forest areas instead on the increase as a result of afforestation, etc., but the extinct species due to past development will never return. After these countries put a higher priority on biodiversity as a qualitative element of the ecosystem, the gap in the level of priority between developed and emerging countries was larger for biodiversity than for primary production.

As discussed above, the results found a tendency to give higher priority to quality-related subjects, such as human health and biodiversity, than to quantity-related ones, specifically social assets and primary production. A possible explanation for this is that quality-related subjects are irreplaceable while quantity-related ones may be replaced by means of afforestation, alternative resources, and use of natural energy.

4.3 Statistical value of preference intensity

The statistical value of the preference intensity can be obtained with use of the random parameter logit model. Table 6 shows the variation coefficients of preference intensity for the G20 and developed, emerging, and individual countries. The variation coefficient is calculated by dividing the standard deviation by the arithmetic mean of preference intensity (Table 4) and represents relative dispersion. This means that a larger value of the variation coefficient reflects greater variation among individuals in a group.

In the G20 and G8, the variation coefficients for all the areas of protection are higher than those of G20 countries excluding the G8 states. Variation coefficients between the preference intensity for the entire G20 and those for G8 countries were not a major difference. But, country-specific variation coefficients are different from these groups significantly. Figure 5 shows a scatter diagram with gross domestic product (GDP) per capita on the horizontal axis and variation coefficients by country on the vertical axis. Dots representing emerging countries are seen on the left-hand side and those representing developed countries on the right-hand side. The diagram also includes regression lines and determination coefficients.

Developed countries have relatively similar variation among individuals. It is found that those of individual G8 countries are proximate in value to one another for any of the areas of protection. Among others, those for biodiversity (ranging 0.82–1.06) and primary production (ranging 0.81–0.96) are close among the eight countries, which shows that the weighting factors and level of dispersion in personal environmental awareness are close among the developed countries. It is therefore thought that there will be little difference in results for the developed countries between the use of the weighting factors for the entire G8 for the LCA and the use of weighting factors for individual countries.

On the other hand, the variation coefficients of preference intensity among the emerging countries are considerably different. In South Korea and Russia, domestic personal environmental awareness is diverse. In Saudi Arabia and India, there is very little difference in terms of environmental awareness among people. In China, Brazil and Argentina showed that the diversity of personal environmental awareness for ecosystem is low. These diverse results indicate that the weighting factors in all emerging countries are poor in representation.

Table 6 The variation coefficients of preference intensity for the G20 and developed, emerging, and individual countries

		Human health	Social assets	Biodiversity	Primary production
G20		1.18	1.58	0.98	0.92
G8		1.21	1.99	0.95	0.91
G20 excluding G8		0.76	1.01	0.86	0.66
Country specific	United States	1.02	1.31	0.87	0.96
	Canada	1.27	1.22	1.06	0.96
	Australia	1.19	1.46	0.96	0.93
	Germany	1.37	1.12	0.82	0.81
	United Kingdom	1.13	1.49	0.91	0.84
	France	1.32	1.50	1.00	0.91
	Japan	1.72	1.42	0.99	0.90
	Italy	0.92	0.90	0.97	0.82
	Korea	1.43	2.13	1.64	1.13
	Argentina	0.41	0.64	0.02	0.13
	Saudi Arabia	0.25	0.22	0.01	0.01
	Russia	1.92	2.21	1.22	0.97
	Mexico	1.09	0.88	1.01	0.87
	Turkey	1.07	1.30	1.30	1.02
	Brazil	1.05	1.62	0.44	0.90
	South Africa	0.94	1.37	0.95	0.92
	China	0.90	0.73	0.16	0.14
	Indonesia	0.75	0.82	1.16	0.20
	India	0.35	0.48	0.03	0.02

Figure 5 also shows the regression line correlated individual variance of weighting factors with GDP per capita. The line showed the weak tendency that the countries with lower GDP per capita including India, China, and Indonesia gave smaller individual variances, and variation coefficient increased with the higher amount of annual GDP per capita. But, this line does not always explain for all G20 countries (low values of determination coefficients). Some other country-specific characteristics except for economic conditions may influence this especially for Russia, Argentina, and Saudi Arabia.

While the variation coefficients are close among the areas of protection in developed countries, the figures are high for human health and social assets and low for biodiversity and

Fig. 4 Relationship between gross domestic product (GDP) per capita and weighting factors by country
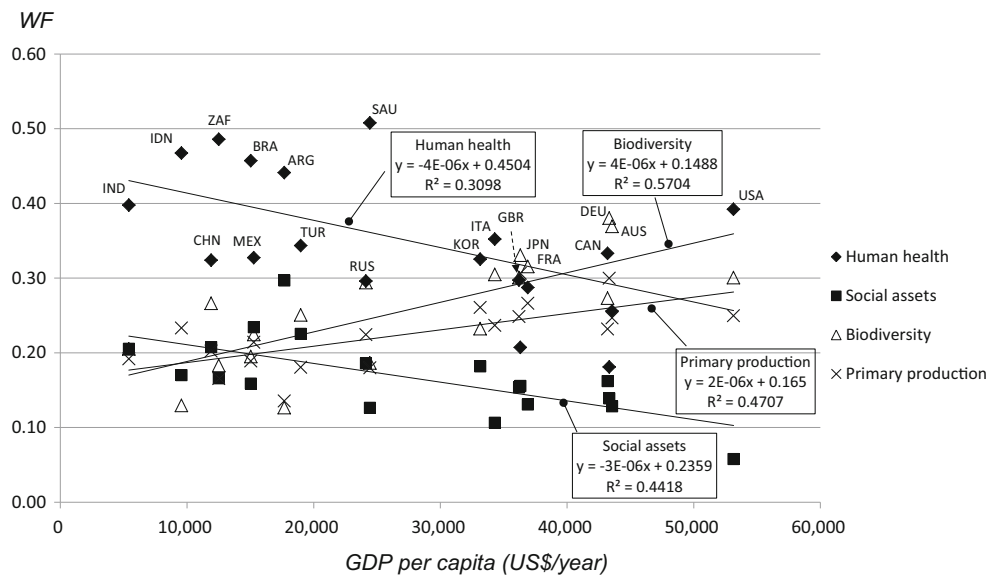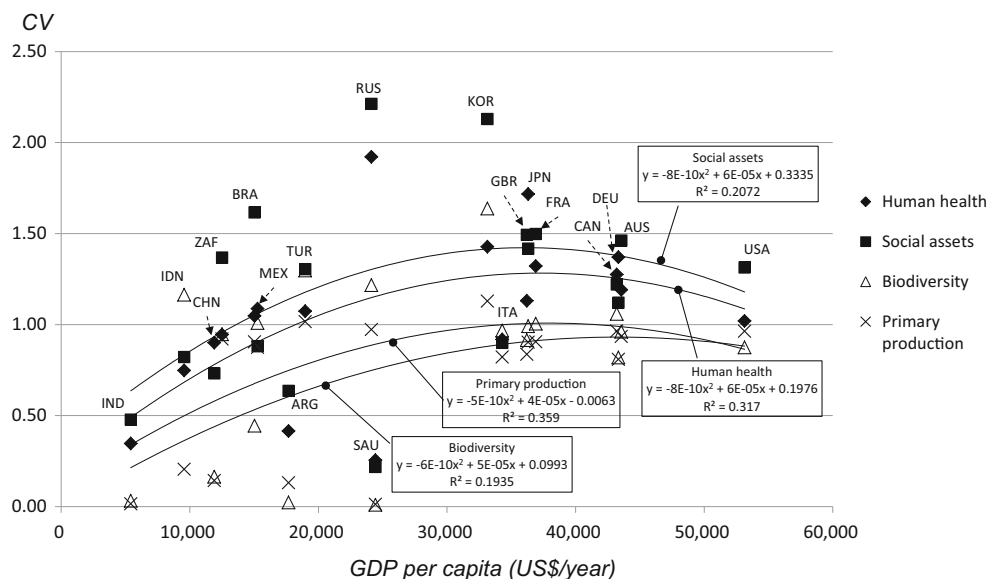
Fig. 5 Relationship between gross domestic product (GDP) per capita and variation coefficients of preference intensity by country

CV

Social assets
$y = -8E-10x^2 + 6E-05x + 0.3335$
$R^2 = 0.2072$

Primary production
$y = -5E-10x^2 + 4E-05x - 0.0063$
$R^2 = 0.359$

Human health
$y = -8E-10x^2 + 6E-05x + 0.1976$
$R^2 = 0.317$

Biodiversity
$y = -6E-10x^2 + 5E-05x + 0.0993$
$R^2 = 0.1935$

◆ Human health
■ Social assets
△ Biodiversity
✕ Primary production

GDP per capita (US$/year)

primary production, especially in many emerging countries. This means that areas of protection relating human society (human health and social assets) are easier for people to express their individual values in their decision.

The variation coefficient varies significantly among the areas of protection. The study found that the difference in tendency between developed and emerging countries is seen not only regarding the weighting factors but also regarding personal difference of environmental awareness.

5 Discussion

5.1 Comparison with the results of LIME2

Table 7 demonstrates a comparison between the results obtained in this study and the weighting factors in LIME2. The following describes commonalities and differences between the steps for calculation of weighting factors in LIME2

(WF$_{LIME2}$) and those for calculation of weighting factors for Japan (WF$_{JPN}$) in this study.

5.1.1 Commonalities

– Respondents are Japanese nationals.
– Conjoint analysis as a method of analysis.
– Composition of the questionnaire.

5.1.2 Differences

– Reference value (LIME2 adopted the reference value in Japan, this study used the reference value in the world).
– Number of samples (LIME2 analyzed 1000 samples, this study 600 in the case of WF$_{JPN}$).
– Survey methods (LIME2 conducted interviews, this study (WF$_{JPN}$ and WF$_{G8}$) adopted Internet surveys in the main survey).

Table 7 A comparison between the results of weighting factors obtained in this study and the weighting factors in LIME2

	LIME2 (Itsubo et al. 2012)			This study (WF$_{JPN}$)			This study (WF$_{G8}$)			This study (WF$_{G20}$)		
	RV (Japan)	$\beta \times RV$	WF	RV (world)	$\beta_{JPN} \times RV$	WF$_{JPN}$	RV (world)	$\beta_{G8} \times RV$	WF$_{G8}$	RV (world)	$\beta_{G20} \times RV$	WF$_{G20}$
HH	6.40E+5 DALY	-1.9E+07	0.26	7.87E+7 DALY	-2.9E+09	0.21	7.87E+7 DALY	-4.0E+09	0.30	7.87E+7 DALY	-4.6E+09	0.34
SA	4.92E+10 US$	-9.7E+06	0.14	4.03E+11 US$	-2.2E+09	0.16	4.03E+11 US$	-1.3E+09	0.10	4.03E+11 US$	-1.8E+09	0.13
BD	9.27E-1 EINES	-2.6E+07	0.37	1.02E+2 EINES	-4.6E+09	0.33	1.02E+2 EINES	-4.5E+09	0.34	1.02E+2 EINES	-3.8E+09	0.29
PP	1.83E+8 ton	-1.7E+07	0.24	1.78E+10 ton	-4.2E+09	0.31	1.78E+10 ton	-3.5E+09	0.26	1.78E+10 ton	-3.1E+09	0.23

HH human health, *SA* social assets, *BD* biodiversity, *PP* primary production

A comparison between the weighting factors in LIME2 and in Japan obtained in this study (WF_{JPN}) reveals that the difference among them is 0.07 or smaller in either study. They have several points in common, including the fact that the weighting factor of biodiversity is highest—at 0.33 in this study and 0.37 in LIME2—while that of social assets was lowest, at 0.16 in this study and 0.14 in LIME2. Meanwhile, some differences are also observed. For example, the gap between the highest and lowest weighting factors is smaller in this study, at 0.13 (=0.33–0.16), than in LIME2, at 0.23 (=0.37–0.14). The order of priority between primary production and human health is not identical, which is due to the point that the level of significance of human health and biodiversity is a little lower and that of social asset and primary production is slightly higher in this study than in LIME2.

The reference value in LIME2 (RV_{JAPAN}) indicates the environmental impacts of the environmental burden generated in Japan. The geographical reach of the impact varies depending on the safeguard subject. For instance, air pollution in urban areas is the range of impact with the greatest contribution to the reference value for human health in LIME2, specifically 6.4 + 5DALY (Itsubo et al. 2010). Many of the health impacts of particulate matters and SO_2 generated in Japan originate in Japan. Damage to biodiversity is also largely due to the change in habitat (Itsubo et al. 2010). The impact of land use change in Japan occurs from Japan; in other words, with respect to the impact on human health and biodiversity, the place of occurrence of environmental burden and where environmental impacts occur are close to each other. However, much of the impact of consumption of wooden and other resources in Japan, as a major importer of mineral resources, fossil fuels, and a large portion of forest resources, occurs outside the country. The reference values for social assets and primary production in LIME2 occur in the Middle East, South America, Australia, Southeast Asia, and other regions far from Japan through mining of mineral resources and deforestation. As a consequence, the weighting in LIME2 tended to place greater emphasis on elements more likely to generate environmental impacts in Japan. In contrast, this study asked questions on awareness of worldwide environmental impacts generated from worldwide environmental burden. The data on regional imbalance of damage are relatively limited, and it is therefore thought that the level of significance of human health and biodiversity was relatively low while that of social assets and primary production was relatively high in comparison with those of LIME2.

Next, the study makes a comparison in the weighting factor results in LIME2 between the entire G8 and G20. The figures in LIME2 are closer to those for the G8 than for the G20. The weighting factors of human health and biodiversity in Japan estimated in this study are lower than those in LIME2 for the reasons described above. However, in the other G8 states, such as the USA and Canada, human health tends to be seen as more significant than in Japan. The weighting factors of human health and biodiversity differ considerably from those in the G20, presumably because the G20 results reflect the environmental awareness in the emerging countries that were significantly different from that among people in Japan.

5.2 Comparison with the result of Ecoindicator'99

This study made a comparison between the weighting factors in Ecoindicator'99 (WF_{EI99}) (Goedkoop and Spriensma 1999) and the results of this study. The following shows the commonalities and differences between the steps for calculation of weighting factors (WF_{EI99}) according to Ecoindicator'99 and those in this study for weighting factors in European countries (UK; WF_{GBR}, France; WF_{FRA}, Germany; WF_{DEU} and Italy; WF_{ITA}).

5.2.1 Commonalities

– Survey was conducted in Europe.
– Weighting given to the areas of protection.

5.2.2 Differences

– Number of areas of protection (three subjects in Ecoindicator'99 and four in this study)
– Reference value (Ecoindicator'99 adopted the European reference value, this study the worldwide reference value).
– Number of samples (Ecoindicator'99 surveyed 82 samples, this study 500 samples in each country surveyed).
– Type of respondents (Respondents in Ecoindicator'99 were experts, in this study general consumers).
– Survey method (Ecoindicator'99 used a mail survey, this study an internet survey).

Since there are a number of differences between Ecoindicator'99 and this study, such as the survey method and the items subject to comparison, it is not entirely possible to compare them. Ecoindicator'99 defined three areas of protection—human health, quality of ecosystem, and resources—whereas this study performed assessments with four areas of protection—human health, social assets, biodiversity, and primary production. Under these circumstances, this study applied two different interpretations, described below, to the comparison.

1. The combination of biodiversity and primary production as areas of protection under this study is regarded as equivalent to the quality of the ecosystem according to Ecoindicator'99 (Table 8). For the purpose of analysis, Ecoindicator'99 classified the respondents into three clusters (hierarchist, egalitarian, and individualist) by environmental awareness. Although the weighting factors found

Table 8 A comparison between the weighting factors in Ecoindicator'99 and European country-specific weighting factors of this study

Ecoindicator' 99 (Goedkoop, Spriensma 1999)				This study			
	WFh	WFe	WFi		WF_{GBR}	WF_{FRA}	WF_{DEU}	WF_{ITA}
Human health	0.4	0.3	0.55	Human health	0.30 (0.40)	0.29 (0.39)	0.18 (0.26)	0.35 (0.46)
Resources	0.2	0.2	0.2	Social assets	0.15 (0.20)	0.13 (0.18)	0.14 (0.20)	0.11 (0.14)
Ecosystem quality	0.4	0.5	0.25	Biodiversity	0.30 (0.40)	0.32 (0.43)	0.38 (0.54)	0.30 (0.40)
				Primary productivity	0.25 (-)	0.27 (-)	0.30 (-)	0.24 (-)

WFh weighting factor for hierarchist, *WFe* weighting factor for egalitarian, *s* weighting factor for individualist

in this study varied from country to country, the weighting factor of the quality of the ecosystem surpassed 0.5 in all the European countries concerned. The weighting according to the egalitarian way of thinking about the environment among the three of clusters mentioned above was close to the results of this study. However, Germany placed a higher weight on the ecosystem, as the weighting factor of the ecosystem in the country was higher than 0.6 (=0.38+0.30), whereas that for human health stood at 0.18.

2. Primary production was among the areas of protection in this study but was out of consideration in Ecoindicator'99. While regarding the weighting factor of biodiversity as equivalent to the quality of the ecosystem according to Ecoindicator'99, this study applied normalization to ensure that the sum of the weighting factors of the three remaining subjects—human health, social assets, and biodiversity—is one. Table 8 shows this result in parentheses. In this calculation, the results for the UK, France, and Italy were close to the weighting factors based on hierarchical thinking, whereas the results for Germany were close to those based on egalitarian thinking.

5.3 Selection of survey procedure and countries

This study determined to conduct main surveys as follows:

- In developed countries, the Internet survey was adopted in order to give higher priority to efficiently securing a large number of samples.
- In emerging countries, interviews were conducted with the priority on minimizing survey bias.
- Developing countries were excluded from the countries subject to the study and the survey covered the G20 states including emerging countries.

The difference of survey procedures between developed countries and emerging countries may cause the difficulty of comparison among the country-specific weighting factors. The findings of the main surveys for developed countries were so desirable (with the results statistically significant) that the use of the Internet in the surveys is thought to have given rise to minor issues.

On the other hand, the pretests conducted in Vietnam and Kenya failed to obtain statistically significant results in terms of currency attributes. The profile in the questionnaire required the respondents to make overall judgments on the tradeoff between environmental and economic attributes. However, they may have little access to environmental information in their everyday life. In countries where few tangible environmental policies had been introduced, it is thought that the respondents had difficulties in precisely expressing their environmental awareness in response to the questionnaire in this study. Meanwhile, the pretest results confirmed that statistically significant data could be obtained by means of interviews in emerging countries.

Exclusion of developing countries impairs the representational nature of globally integrated factors, but this study opted to give higher priority to obtaining highly reliable results by surveying emerging and developed countries, where the level of understanding of environmental information was high. The inclusion of developing countries in the development of weighting factors would be the subject of future investigation.

6 Conclusions

This study calculated weighting factors in the G20 countries with a view to developing weighting factors that can be used in any country. After conducting a uniform questionnaire in the G20 member countries, the study performed a statistical analysis to estimate weighting factors for individual countries, G8 developed countries, emerging countries (i.e., G20 countries excluding G8 countries), and the full G20. In emerging countries, interviews were conducted with a focus on understanding of the questions in the questionnaire and minimization of bias. In developed countries, Internet surveys were

conducted in priority consideration of the survey budget and maximization of the number of samples. In both types of surveys, random sampling was implemented, and a total of 6400 responses were obtained.

In all countries surveyed, statistically significant results were obtained at the level of 1 % in all environmental attributes (all p values for the safeguard subject coefficients were less than 0.0001). After normalization to ensure that the sum of weighting factors of the four areas of protection was one, the weighting factor in the full G20 was the highest for human health, followed by biodiversity and primary production. Meanwhile, social assets were relatively poorly weighted. In the G8, the values for biodiversity and primary production were higher than in the full G20. The value of biodiversity was slightly higher than the value for human health. In emerging countries, health impacts were particularly weighted, while the three others were almost equally weighted. On a country-by-country basis, the weighting factors varied hugely depending on the country, but they tended to be close among the developed countries. Among the emerging countries, the factors varied considerably from country to country. In developing countries, the responses involved a serious bias, suggesting difficulty in reflecting personal environmental awareness. Therefore, it is considered that the results obtained in the G8 may be used for other developed countries, while it is not fully possible to use the findings concerning the emerging countries as a whole for other emerging countries not subject to this survey, or for developing countries.

Each of the areas of protection has close correlations with GDP per capita. The higher the GDP per capita, the higher the weighting factor for biodiversity and primary production. The lower the GDP per capita, the higher the weighting factor for human health and social assets. These findings will be helpful to assessment of any country other than those assessed in this study.

The calculation results of random parameter logit model showed that weighting factors and level of dispersion in personal environmental awareness are close among the developed countries. On the other hand, the variation co-efficients of preference intensity among the emerging countries are considerably different. The study found that the difference in tendency between developed and emerging countries is seen not only regarding the weighting factors but also regarding personal difference of environmental awareness.

The findings of this study could be used for integration of environmental impacts by multiplying the results of characterization calculated for individual areas of protection by the normalized weighting factors. We prepared 3 geographical scales of weighting factors; 1. the full Group of Twenty (G20; consisting of 19 countries excluding the European Union), (2) Group of Eight (G8; eight countries) and group of G20 countries excluding the G8 states (11 countries), and

(3) in each of the G20 countries. These weighting factors can be chosen by the aims of application. In general, the reliability of country-specific weighting factors is higher than that of world scale. If LCA user wish to share the calculated results internationally (e.g., among the member countries of European Union), the usage of weighting factors of the group countries (e.g., WF_{G8}) would be useful. It is impossible to apply it to all countries, but this study is the first attempt to develop and examine weighting factors covering the G20 countries, which make up a large proportion of the worldwide economy. It is thought to be of significant help for implementation of LCA, which reflects environmental awareness of different countries in the world.

References

Ben-Akiva ME, Lerman SR (1985) Discrete Choice Analysis: Theory and Application to Travel Demand. MIT Press, Cambridge

Finnveden G, Eldh P, Johansson J (2006) Weighting in LCA based on Ecotaxes development of a mid-point method and experiences from case studies. Int J Life Cycle Assess 11:81–88

Food and Agriculture Organization of the United Nations (2006) State of the World's Forests 2012, ISBN 978-92-5-107292-9

Goedkoop (1995) The Eco-indicator 95. NOH report 9523. Pré Consultants, Amersfoort

Goedkoop M, Spriensma R (1999) The Eco-indicator 99, A damage oriented method for Life Cycle Impact Assessment, Methodology Report

Green PE, Krieger AM, Agarwal MK (1991) Adaptive conjoint analysis, some caveats and suggestions. J Market Res 28:215–222

Hauschild M, Wenzel H (1997) Environmental Assessment of products. Volume 2: Scientific background. Chapman & Hall, London

Huppes G, Davidson MD, Kuyper J, van Oers L, Udo de Haes HA, Warringa G (2007) Eco-efficient environmental policy in oil and gas production in The Netherlands. Ecol Econ 61:43–51

ISO 14040 (2006) International standard, Environmental management - Life cycle assessment - Principles and framework

ISO 14044 (2006) International standard, Environmental management - Life cycle assessment - Requirements and guidelines

Itsubo N (2000) Screening life cycle impact assessment with weighting methodology based on simplified damage dunctions. Int J Life Cycle Assess 5(5):273–280

Itsubo N, Sakagami M, Washida T, Kokubu K, Inaba A (2004) Weighting across areas of protection for LCIA through the application of conjoint analysis. Int J Life Cycle Assess 9:196–205

Itsubo N, Inaba A, Ii R, Ikaga T, Kubo T, Sakagami M, Nagata Y, Hama Y, Hayashi K, Hirosaki J, Motoshita M (2010) LIME2 –an environmental impact assessment method supporting decision making (in Japanese)

Itsubo N, Sakagami M, Kuriyama K, Inaba A (2012) Statistical analysis for the development of national average weighting factors—visualization of the variability between each individual's environmental thoughts. Int J Life Cycle Assess 17(4):488–498

McFadden D (1974) Conditional Logit Analysis of Qualitative Choice Behavior. In: Zarembka P (ed) Frontiers in Econometrics. Academic Press, pp 105-142

Müller-Wenk (1994) The Ecoscarcity Method as a Valuation instrument within the SETAC-Framework, in Integrating Impact Assessment into LCA, SETAC-Europe, Bruxelles, pp 115-120

NOAA Panel (1993) Arrow K, Solow R, Portney PR, Leamer EE, Radner R, Schuman H. Report of the NOAA Panel on Contingent Valuation, January 11

Pizzol M, Weidema B, Brandão M, Osset P (2014) Monetary valuation in Life Cycle Assessment: a review. J Clean Prod 86(1):170–179

Soares SR, Toffoletto L, Dechênes L (2006) Development of weighting factors in the context of LCIA. J Clean Prod 14:649–660

Steen B (1999) A Systematic Approach to Environmental Priority Strategies in Product Development (EPS) Version 2000 – Models and Data of the Default Method

Train K (2003) Discrete Choice Model with Simulation, 2003

Weidema BP (2009) Using the budget constraint to monetarise impact assessment results. Ecol Econ 68:1591–1598

World Bank (2014) World Development Indicators database, Accessed on 16 July 2014. http://data.worldbank.org/data-catalog/world-development-indicators

Yasui I (1998) A new Scheme of Life Cycle Impact Assessment Method Based on the Consumption of Time. 3rd Int. Conf. on Ecobalance, Tsukuba, p 89