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DEVELOPMENT OF GLOBAL SCALE LCIA METHOD

Preface

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1 Background

The concept of lifecycle assessment (LCA) had appeared in the beginning of 1970s, and lifecycle impact assessment (LCIA) methods had been developed mainly in Europe and the USA since 1990s. In the early stage of LCIA, the middle point approaches such as Eco Indicator 95 (Goedkoop 1995) and the method using Distance to Target (DtT) like Eco-point method (Buwal 1998) were popular, but recently many methods on the endpoint approaches have been developed. Eco Indicator 99 (Goedkoop and Spriensma 2000) developed in the Netherlands and EPS (Environmental Priority Strategies) method (Steen 1999) in Sweden might be thought to be the primitive models in the end of 1990s. They were followed by LIME (life cycle impact assessment method based on endpoint modeling) (Itsubo 2012) in early 2000s in Japan. And then, ReCiPe was developed as the method following Eco Indicator 99 (Goedkoop et al. 2009; Huijbregts et al. 2016).

In LCIA methods on the endpoint approaches, EPS (Steen 1999) and LIME (Itsubo 2012) paid attention from the viewpoint of monetary valuation of the environmental impacts, where the damages on the endpoints were converted into the currencies. Although the monetarization methods of the environmental impacts have been studied for many years in the academic field, they became recently to be one of the business tools, which concrete methods are shown currently by ISO/DIS 14008 (2018), “Monetary valuation of environmental impacts and related environmental aspects—Principles, requirements, and guidelines,” and which should be used by ISO/CD 14007 (2018), “Determining environmental costs and benefits—Guidance,” that will be published within a year.

One of the backgrounds of these ISO publications is the worldwide interests on the climate change. The Paris Agreement was adopted by consensus of 196 state parties on 12 December 2015. Following it, Task Force on Climate-Related Financial Disclosures (TFCD) published the work and recommendations in 29 June 2017 to “help companies understand what financial markets want from disclosure in order to measure and respond to climate change risks, and encourage firms to align their disclosures with investors' needs.” (TFCD 2018). It means that the financial sectors push the companies to reduce greenhouse gases (GHGs) using the market mechanism. Also in the field of ISO, ISO/NP 14097 (2018) “Framework and principles for assessing and reporting investments and financing activities regarding climate change” will be published within a year. Monetary valuation of the impacts caused by of GHGs shown in ISO/DIS 14008 (2018) will be more substantial in near future.

Although climate change could be the current most interesting topic in the world, other environmental impacts should not be forgotten because the trade-off relation between a few environmental impacts sometime occurred. In this sense, EPS and LIME have been developed to be able to evaluate not only climate change but also many other impacts. The chief characteristic of monetarizing environmental impacts is to sum up the endpoint damages into a currency that gives us the solution of the trade-off problems.

Needless to say, there are so many environmental aspects from the local or regional scale to the global scale. For example, climate change is completely global but air pollution and biodiversity are sometime local and sometime regional. Both environmental impacts on the global scale and local/regional scale shall be evaluated. However, the LCIA methods have been developed in the world do not always apply to the entire world. Several methods consider the spatial differences of environmental impacts, but most of these methods fail to clarify the relationship between causing area and affected area. The LCIA methods to be able to apply to the entire world shall be developed as soon as possible.

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In this special issue, the articles related to LIME-3 are introduced, which have been developed in Japan to follow LIME-1 and LIME-2 using the monetary valuation method and to enable the global scale environmental impacts to be assessed on each country and/or region.

2 LIME method

The first version of LIME, LIME-1, was developed in 2000 by the Japanese national project of LCA on 1998–2000 supported by METI (Ministry of Economy, Trade and Industry), when the basic methodology of LIME was established. LIME has three steps of LCIA (characterization, damage assessment, and weighting) and conjoint analysis was used for the weighting. LIME-1 had 11 impact categories for characterization (air pollution, human toxicity, ozone layer depletion, global warming, ecotoxicity, acidification, eutrophication, ozone creation, land use, solid waste, and resource consumption) and 4 endpoints (human health, social assets, biodiversity, and primary production). LIME-2 was developed by the 2nd National Project of LCA on 2004–2006, where indoor air pollution and noise were added for the characterization and the conjoint analysis was conducted by almost 1000 respondents of all Japan. LIME-1 and LIME-2 reflected the environmental conditions in Japan and the environmental thoughts of the Japanese people; therefore, it was not suitable for assessing the environmental impacts in other countries/regions (Itsubo and Inaba 2012; Itsubo et al. 2012, Itsubo et al. 2015).

LIME-3 was developed in 2016, where the methodology of LIME-1 and LIME-2 was expanded in order to be used in the world. For characterization, nine impact categories (climate change, air pollution, photochemical oxidants creation, water consumption, land use, mineral resource consumption, fossil fuel consumption, forest resource consumption, and solid waste) were selected and four endpoints (human health, social assets, biodiversity, and primary production) were the same as LIME-1 and LIME-2. The conjoint analysis for weighting was conducted in all G20 countries.

Figure 1 shows the basic structure of LIME-3 and Table 1 shows the relationship between the impact categories and the endpoints. The unshaded columns of Table 1 were calculated by LIME-3. For example, the health damage of climate change includes malaria, cardiovascular disease, disaster, malnutrition, and diarrhea. The light-shaded columns were judged after consideration to have a small impact. On the other hand, those in the dark-shaded columns are likely to have a significant impact, but their calculations were difficult even with the latest knowledge in each research field.

As shown Table 1, for climate change, its impact on both human health and biodiversity was calculated. Concerning the impact on human health, the quantity of damage from CO_2 emissions was calculated for each disease (malnutrition, diarrhea, cardiovascular disease, malaria, coastal flooding, and inland flooding). It was found that a greater impact was made by malnutrition (26.8 × 10–8 years/kgCO_2) and diarrhea (9.0 × 10–8 year/kgCO_2), secondary disasters that were not taken into account in previous studies, than by the direct impact of temperature changes (cardiovascular disease (0.4 × 10–8 years/kgCO_2)). The details of the methodology and result of damage factors caused by climate change were described by Tang et al. (2018a). Damage to biodiversity caused by climate change was assessed by analyzing the changes in the vegetation distribution of 250 species of plants in Japan. The analyses were made by using a statistical model, and the length of time before extinction was thus calculated (Tang et al. 2018b). Further, combined with the risk of extinction on the continental scale, these results were used to expand the calculation to a global scale.

Regarding the damage model of air pollutants (SO_2, NO_2, black carbon, and organic carbon) (Tang et al. 2018c) and photochemical oxidant substances (Tang et al. 2018d), transboundary effects have been taken into account with the application of a global chemical transport model. LIME-3 involves analyses of both the region from where the pollutant is emitted and other regions where the damages occurred, enabling the avoidance of underestimations.

In LIME-3, water use was included as a new impact category to develop a method of assessing the impact on health. The expected value for the number of people with health damage caused by the consumption of freshwater was calculated for each country by conducting a multiple linear regression analysis based on statistical data on each country of the world. It was found that the damage quantity is greater in developing countries with serious water shortages than in developed countries. Damage factors related with water use were described by Motoshita et al. (2018).

A method of assessing damage to biodiversity and primary production caused by land use was developed. A method of assessing the increment in the risk of the extinction of vascular plants in Japan that would be caused by land transformation was developed, and analyses of 2000 species were made. The representative value for damage factors in Japan was calculated by undertaking an analysis for each type of land use, and then damage factors expanded to 193 countries around the world were developed by using data from IUCN. Yamaguchi et al. (2018) described the method and damage factors related with biodiversity caused by land use.

A method of assessing damage from resource consumption was developed for each endpoint (social assets, primary production, and biodiversity). The area of land that was transformed as a result of mining was calculated for each resource and each country in consideration of the grades of resources and the mining methods. Damage factors reflecting the environmental conditions of the mining country were calculated by using the data on the number of endangered species and the

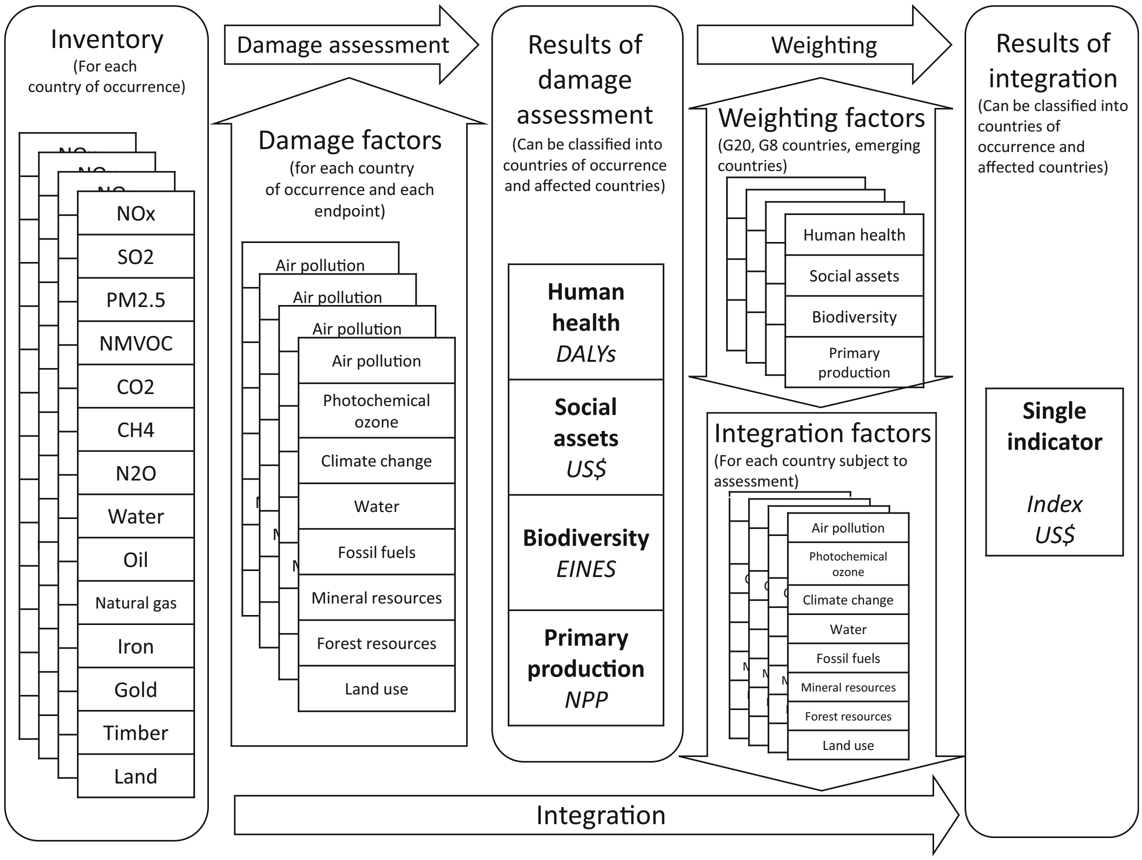

Fig. 1 Conceptual figure of LIME-3

amount of primary production in the country. The reflection of trades between consumer countries and mining countries enabled the establishment of a method that enables an analysis of the damage to the mining country caused by the consumption of a unit of resources in the consumer country.

In terms of weighting, a questionnaire survey of all the G20 member countries was conducted. An interview survey (door-to-door survey/central location survey) was conducted for emerging 11 countries, giving priority to respondents' understanding of the survey sheet's content and minimization of their bias. For developed countries, an internet survey was adopted after confirming the result of the pretest that the difference between the results of the internet survey and the interview survey was small. Random sampling was adopted for both surveys, and 200 to 250 samples were taken from each emerging country and 500 to 600 from each developed

Table 1 List of category endpoint considered in LIME-3

Areas of protection and damage indicator	Human health	Social assets	Biodiversity	Primary production
Impact category	DALY	US$	EINES	NPP
Climate changes	Malnutrition, diarrhea, cardiovascular disease, malaria, coastal flooding, and inland flooding		Terrestrial ecosystem (vascular plants)	
Air pollution	Chronic death, acute death, respiratory diseases			
Photochemical oxidants	Chronic death, acute death, respiratory diseases			
Water resource consumption	Waterborne infectious diseases, nutritional deficiency			
Land use			Terrestrial ecosystem (vascular plants)	Terrestrial ecosystem
Resource consumption (fossil fuels and mineral resources)		User cost	Terrestrial ecosystem (vascular plants)	Terrestrial ecosystem
Forest resource consumption			Terrestrial ecosystem (vascular plants)	Terrestrial ecosystem

EINES expected increase in number of extinction species

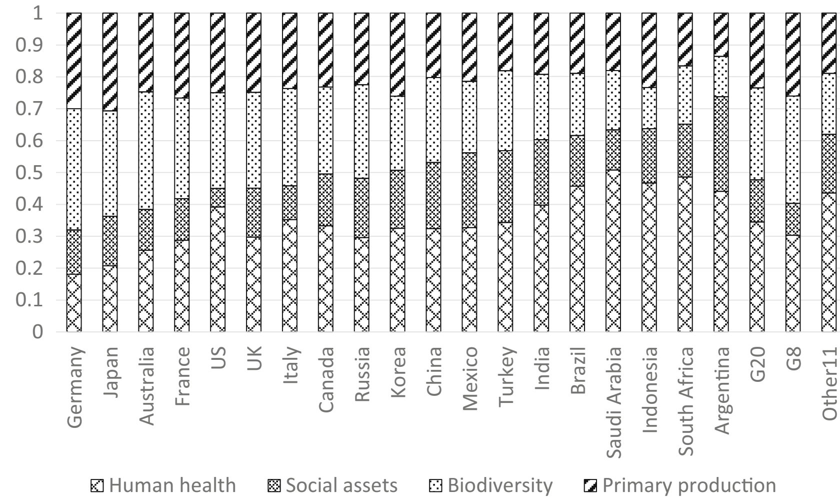

Fig. 2 Results of weighting factor (WF1) calculations (Itsubo et al. 2015)

country. A total of 6400 responses were obtained. The difference in environmental awareness between individuals was examined by using the random parameter logit model.

Two types of weighting factors—non-dimensional weighting factor (WF1) and economic weighting factors using willingness to pay (WF2)—were obtained. Figure 2 shows the results of the calculation of the weighting factors (WF1) of all the G20 countries, developed countries (G8), emerging countries (G20 countries excluding G8), and each G20 member country, which were made non-dimensional so that the sum of the weights of the four items would be 1. Among developed countries (G8), values for biodiversity and primary production are higher than among G20 countries. On the other hand, the weight of human health (0.44) is especially heavy in emerging countries, while the weights of the three other items are almost equal to each other (0.18 for social assets, 0.19 for biodiversity, and 0.19 for primary production). The weighting factors of the respective countries do not differ significantly among developed countries, but vary greatly among emerging countries.

Figure 3 shows the economic weighting factors of human health (US$/1 year-DALY) using willingness to pay (WF2) in each country, which were higher in emerging countries than those in developed countries. These results were almost the same in the other three endpoints although their absolute values were different. It might be caused by the circumstances that the environmental problems are more serious in emerging countries than developed countries. It should be reflected by environmental awareness in G20 countries. The details are shown by Itsubo et al. (2018b) and Murakami et al. (2018).

3 Limitation of LIME-3 on LCIA for global scale

As described above, while LIME-3 covers nine areas, including climate change and air pollution, it cannot be said that the

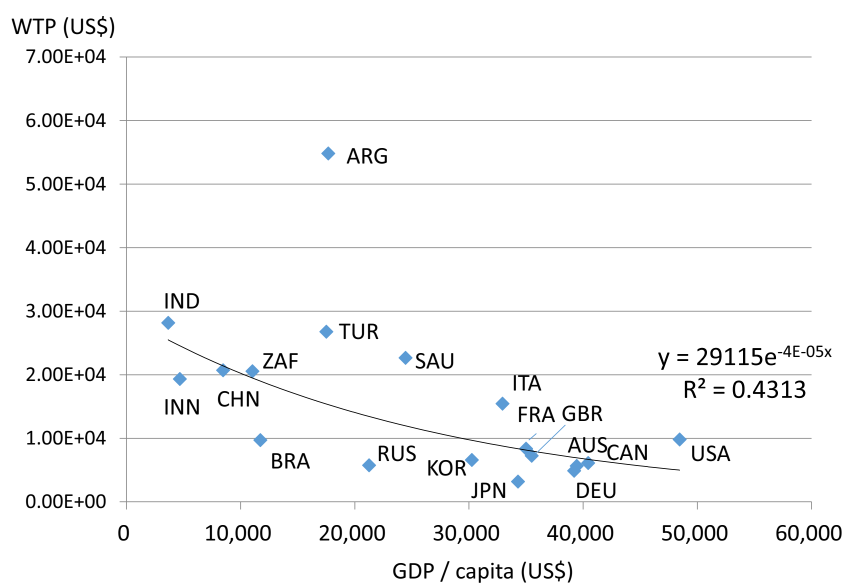

Fig. 3 Results of calculations of the weighting factor (WF2) on human health in G20 countries (Murakami et al. 2018)

range of categories is wide enough compared to other LCIA methods. For the development of damage factors concerning ecotoxicity and human toxicity, eutrophication, acidification, and noise are needed for the global scale assessment.

Also in terms of weighting, the weighting factors of G20 countries were calculated in LIME-3, but the surveys for developing countries should be conducted. In our experience, the survey sheet for conjoint analysis is not sufficiently understood in developing countries. Weighting factors representing the entire world, including developing countries, need to be developed in the future.

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