Chapter 15
Weighting

Norihiro Itsubo

Abstract In the ISO 14044 standard 2006, weighting is an optional step in life cycle impact assessment (LCIA). It enables the user to integrate various environmental impacts in order to facilitate the interpretation of the life cycle assessment (LCA) results. Many different weighting methodologies have been proposed and several are currently being used regularly. Most existing studies apply the average of the responses obtained from the people (i.e. the decision makers) that were sampled. Others believe that weighting factors should be based on the preferences of society as a whole so that LCA practitioners can successfully apply them to products and services everywhere. This chapter classifies methods of weighting into three categories: proxy, midpoint, and endpoint methods. Results using proxy methods, such as MIPS (Material Input Per Service), CED (Cumulative Energy Demand), TMR (Total Material Requirement), Ecological Footprint, and CExD (Cumulative Exergy Demand), are fairly easy to understand because physical quantities such as weight and energy are used. The advantages of midpoint methods include compliance with the ISO framework and how it permits weighting that uses characterisation results. Endpoint methods allocate weights to Areas of Protection (AoP) rather than at midpoints, reducing the number of subject items and simplifying interpretation. Recently, weighting with endpoint methods has attracted attention due to the advancement of characterisation methodologies of this type. This chapter presents the different features of weighting and integration approaches applied in LCIA. The important differences and future problems concerning five key endpoint weighting methods are described. It concludes with a brief summary of the key features of the weighting methods introduced herein.

Keywords Economic assessment • Endpoint approach • LCA • LCIA • Life cycle assessment • Life cycle impact assessment • Midpoint approach • Weighting

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1 Introduction

The types of potential environmental impact associated with a product life cycle vary widely from highly local, such as indoor air pollution and noise, to global, such as global warming and resource depletion, as discussed in the previous chapters in this book on characterisation (Chaps. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, and 13). However, products or systems developed to improve the environment often focus on one or only a few environmental problems in order to alleviate or reduce their impact. This is the case in biofuels which are expected to help reduce the risk of global warming because their combustion is considered carbon-neutral. However, while potentially reducing the risk of global warming, biofuels create a relatively greater impact to water resources by using crops as their raw materials and the occupation of land may impact biodiversity. Realising that products and services are associated with diverse environmental impacts, we need to assess them by considering the balance among their environmental impacts in an explicit manner and in accordance with the defined goal of the study, to ensure that the conclusions take the whole relevant spectrum of impacts into account.

Life cycle impact assessment (LCIA) covers multiple impact categories in the characterisation phase. The ISO standard requires that "The selection of impact categories shall reflect a comprehensive set of environmental issues related to the product system being studied, taking the goal and scope into consideration" (ISO 2006). In Europe, a default list of 14 impact categories is recommended for studying environmental footprints, and where any one of these is excluded, validity of the exclusion needs to be explained (EC 2013). Characterisation factors express the relative ability of individual substances to contribute to an impact category and enable calculation of aggregated impact results for each of the multiple impact categories. It provides no support for the aggregation or comparison of scores for different impact categories. Therefore, if a trade-off between impact categories is created in a comparison of products, the final decision on which choice is preferable requires the use of some type of value judgment, i.e. a weighting process based on the perceived importance of the impact categories to the decision maker. How to weigh or balance the impact scores is left to the practitioner and the stakeholders involved in the study. It is important to recognise that the absence of assigning weights to impact scores results in equal weighting by default.

2 Historical Development of Weighting Methods

Life Cycle Impact Assessment (LCIA) dates back to the latter half of the 1980s, when the Society of Environmental Toxicology and Chemistry (SETAC) adopted LCA as a theme for studies and began to discuss LCA studies regularly at its annual meeting. The Code of Practice (Consoli et al. 1993) issued by SETAC in 1993 included valuation as a step in the framework for LCIA, and weighting was thus

recognised as a step of LCIA. Research activities aimed at developing a weighting method were further intensified. Through the early 1990s, pioneering institutions such as CML (Heijungs et al. 1992) and countries in Northern Europe (Lindfors et al. 1995; Wenzel et al. 1997) issued LCIA guidelines one after another, aiming to establish a framework for LCIA with consecutive steps of **characterisation**, **normalisation** and **weighting**. This work along with others was reflected in the ISO framework which evolved in parallel during the second half of the 1990.

In almost the same period, the Swiss Ecoscarcity method (Ahbe et al. 1990; Braunschweig and Müller-Wenk 1993) and the Swedish EPS method (Steen and Ryding 1992) were proposed. These methods had no explicit characterisation step but directly correlated substance emissions of concern with valuation without the process of characterisation.

In the latter half of the 1990s, methods for integrating characterisation with valuation were proposed. Most notable was the distance-to-target method included in the Eco-Indicator 95 method (Goedkoop 1995) and EDIP97 (Wenzel et al. 1997) which attracted much attention. Development of weighting factors with this method requires two values, desired and actual, which differ among countries. Therefore, studies for developing weighting factors reflecting standards, etc. of each country (e.g., Hauschild and Wenzel 1998; Lee 1999; Itsubo 2000; Matsuno et al. 1999) were performed in various countries.

At the time it was recognised that while a single index obtained through valuation makes it easy to interpret the result, there were issues concerning reliability and representativeness of the assessment results. In ISO's tasks of establishing an international standard for LCIA, there was a great amount of discussion on whether or not to recognise weighting as a formal step in LCIA.

From the latter half of the 1990s until the 2000, development of damage assessment methods was intensified after their importance was pointed out by Müller-Wenk (1997) and Hofstetter (1998). Müller-Wenk developed a damage factor for assessing the impact of traffic noise on health. Hofstetter (1998) and Krewitt et al. (1999) developed a factor for assessing the impact of air pollutants on health. Jolliet and Crettaz (1997) developed one for assessing the damage toxic chemicals have on health. All these applied a damage index based on lost life expectancy. Lindeijer (2000) developed a damage factor for assessing the impact of land use on the growth of plants. Van de Meent (1999) developed a damage factor for assessing the impact of chemical substances on loss of species. Goedkoop et al. in the EI99 method developed a damage factor for assessing the impact of acidification and eutrophication on loss of plant species (Lindeijer 2000; van de Meent 1999). Given the progress in the research and development concerning damage assessment, development of a method of weighting by comparing endpoints attracted attention. Several methods went on to support obtaining a single index by weighting and aggregating endpoint scores, including the revised version of the Eco-indicator (Goedkoop and Spriensma 1999), the Life-Cycle Impact assessment Method based on Endpoint modelling (LIME; Itsubo and Inaba 2005), the revised version of the EPS (Steen 1999), and the revised version of ExternE (EC 2005), all of which were developed in the above mentioned period. Many of

these methods were also developed through studies in which economic indices were used in attempts to calculate external costs.

Historically, the development of weighting methods was undertaken mainly in industrialised countries such as Japan and European countries. Currently, weighting factors are also being developed for emerging countries such as China (Wang et al. 2011). The hope is that assessment methods covering the entire world instead of particular regions will be developed in the future.

3   Purpose of Weighting

Figure 15.1 shows characterisation results from an LCA of beverage containers (aluminium cans, plastic bottles, and standing pouches, one 350 ml unit of each) (Yoshimura et al. 2011). The figure shows the trade-off between environmental impacts for the three containers. The standing pouches allow reduction of resource consumption; especially the use of fossil resources. The global warming impact was also found to be smaller for standing pouches due to reduced energy used in production, but the difference is not as great as for resource consumption, because the material recycling rate of standing pouches is relatively lower, while it permits reduction of carbon dioxide (CO_2) emission in the production of its materials, and because the rate of thermal treatment is high, which means that the amount of CO_2 emitted in disposing of standing pouches is larger than that for the other containers. With regard to a third impact category, photochemical oxidants, the value for standing pouches is the largest among all three types of containers because volatile organic compounds (VOCs) are emitted from solvents when films consisting of multiple layers are pressure-bonded to each other.

Figure 15.2 shows the results of weighting across the same three impact categories shown in Fig. 15.1, and others. Thus, weighting allows aggregation of different environmental impacts into a single score. We can say it is a useful step because it resolves trade-offs in an explicit and transparent way in support of decision-making.

Weighting based on valuation is used to make it easier to transmit information to general consumers as well as for decision-making by product designers and for other purposes. For example, the French supermarket chain Casino calculated a single index of beverages by valuating impacts related to global warming, water contamination, and water consumption. Puma, a sportswear manufacturer, valuated five types of environmental impacts, including global warming and water use, in monetary terms and disclosed its aggregated yearly environmental impact in a report (Puma 2010; PwC World Watch Issue 2011). In recent years, we have seen cases where the results of valuation are used for calculation of an environmental index that takes into account functions and values of products, presented as an environmental efficiency. Toshiba used weighting factors of LCA for comprehensive environmental efficiency calculation called Factor T (Toshiba 2009). BASF suggests and uses a method of showing environmental efficiency by
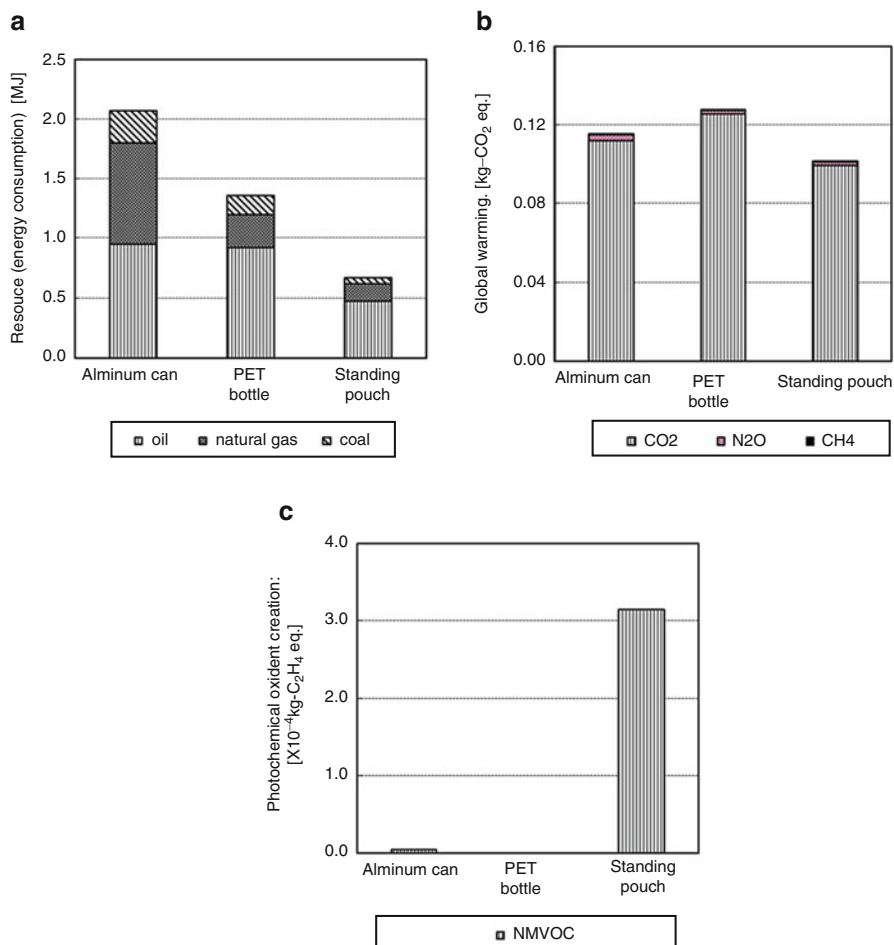
Fig. 15.1 Characterisation results of an LCA on beverage containers (aluminium cans, plastic bottles, and standing pouches, one 33 cl 350 ml unit of each) (**a**) energy consumption, (**b**) global warming, (**c**) photochemical oxidant

diagrammatically indicating relative relations between costs and environmental impacts (Saling et al. 2002). In this way, weighting is used by many companies to derive an environmental index from a comprehensive set of impact indicators.

Weighting environmental impacts offers the following benefits:

(a) Any trade-offs between the included impact category results are resolved in an explicit and transparent way and the results are prepared to be shown in a single index.

(b) It permits easy interpretation and communication of results so it is useful when transmitting information via environmental reports, etc.
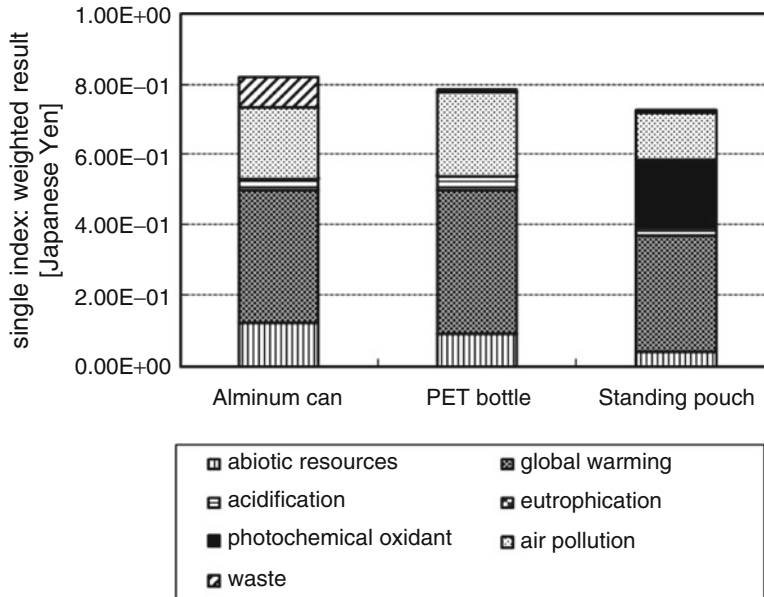
Fig. 15.2 Calculated results of a weighting across impact categories including energy consumption, global warming and photochemical oxidants

(c) It is highly applicable for tools for other environmental assessment tools such as environmental accounting (Bringezu et al. 1998) and environmental efficiency.

Common to all of these examples multiple environmental impacts are weighted and aggregated to be shown with a single index. However, the method for doing this process differs.

4 Restrictions on the Use of Weighting in International Standards

As previously described, weighting is a convenient method for resolving trade-off situations, but the ISO standard for LCA (ISO 2006) puts certain restrictions on its use. This is because value judgment is unavoidable in weighting. Environmental impacts include impacts on human health, ecosystems, and a host of other subjects. It is not possible to summarise such diverse impacts and show them with a single index only based on scientific criteria, a value judgment is inevitable in such a process.

Values differ among individuals and societies. Therefore, different stakeholders will often have different values and require different weighting factors, which could

result in different conclusions. LCA results are used either to support improving products without disclosing the results (internal use) or for supporting assertions that the given products are eco-friendly by disclosing them to the public (external use). Above all, weighting could cause problems when applied in LCAs where results are intended for external use. Suppose that weighting is applied in a comparison between a company's product and a competing product from another producer, and the environmental impact of the company's product is found to be less than that of its competitor's when a particular set of weighting factors is applied. If use of another set of plausible weighting factors results in a different conclusion, and the company only discloses the result that is advantageous for itself, the competitor whose product was compared with the company's may suffer in a market that gives priority to environmental performance of the products.

To prevent such inappropriate use of weighting, and in general the influence of value-based choices in comparative assertions, ISO 14044 prescribes the following. First, the elements of LCIA are divided into mandatory elements and optional elements. Weighting is positioned as an optional element along with normalisation and grouping. While it is mandatory to conduct characterisation in LCIA, whether or not to perform weighting is determined on a case-by-case basis in accordance with the goal of the study and the target audience of the report. In other words, even when use of weighting is the main purpose of LCA, it is required to at the same time practice characterisation. Second, ISO 14044 also restricts use of weighting. Above all, it prohibits comparison of a company with the goal of the study and the target audience of the report. In other words, there are restrictions for when use of the results are for comparative assertion to be disclosed to the public.

On the other hand, ISO 14044 does not restrict the use of weighting in comparisons for other purposes, such as informing internally or disclosing to the public results of comparison between a company comparison to the As an alternative to quantitative weighting, the ISO standard also mentions the possibility of grouping or ranking the impact categories according to their importance. In this way, an alternative that scores best in all the most important impact categories may be identified as the best without resorting to a weighting, even if there are trade-offs to some of the other impact categories.

5 Different Approaches to Weighting

Generally, weighting means procedures for obtaining a single index based on subjective evaluations of different environmental impacts. The various methods of assessment with the use of weighting factors can be classified as follows.

1. Proxy method – weighting factor is directly applied to the inventory data.

$$I_1 = \sum_s \left(Inv(X) \times WF_1(X) \right) \tag{15.1}$$

I_1 indicates the result of valuation, $Inv(X)$ is the inventory data of substance X, and $WF_1(X)$ is the weighting factor of substance X. This method enables obtaining the valuation result by directly multiplying the inventory data by the weighting factor. The weighting factor is set for each substance.

2. Midpoint method – the value obtained by multiplying the characterisation factor of the midpoint by the inventory data is converted to a non-dimensional figure or expressed in a common unit across the different impact categories and then multiplied by the weighting factor.

$$I_2 = \sum_{\text{Impact}} \sum_{X} \left(\frac{Inv(X) \times CF^{\text{Impact}}(X)}{NV^{\text{Impact}}} \times WF_2{}^{\text{Impact}} \right) \tag{15.2}$$

I_2 indicates the result of valuation, $CF^{\text{Impact}}(X)$ is the midpoint characterisation factor of substance X in the impact category (Impact), NV^{Impact} is the **normalisation reference** for the impact category (Impact), and WF_2 is the weighting factor of the impact category (Impact).

The result obtained by multiplying the characterisation factor of midpoint type by the inventory data is normalised to remove any bias caused by the different dimensions of the impact categories. Weighting is then performed by multiplying the value thus obtained by a non-dimensional weighting factor. A weighting factor is set for each impact category. The yearly amount of environmental impact in the subject country or region is used as the **normalisation value** in many cases (see this volume, Chap. 14 on normalisation by Alexis Laurent and Michael Hauschild).

3. Endpoint method (type1) – the value obtained by multiplying the characterisation factor of the endpoint by the inventory data is converted to a non-dimensional figure or expressed in a common unit across the different endpoint categories and then multiplied by weighting factor.

$$I_3 = \sum_{\text{Impact}} \sum_{\text{Endpoint}} \sum_{X} \left(\frac{Inv(X) \times CF^{\text{Impact}}(\text{Endpoint}, X)}{NV(\text{Endpoint})} \times WF_3(\text{Endpoint}) \right) \tag{15.3}$$

I_3 indicates the result of valuation, $CF^{\text{Impact}}(\text{Endpoint}, X)$ is the endpoint characterisation factor of substance X for the endpoint (Endpoint) in the impact category (Impact), $NV(\text{Endpoint})$ indicates the **normalisation value** of Endpoint, and $WF_3(\text{Endpoint})$ is the weighting factor of the Endpoint.

In this case, the inventory data is multiplied by the characterisation factor of the endpoint type and then divided by the **normalisation reference** that has the same dimension as the characterisation result. Weighting is then performed by

multiplying this value by a non-dimensional weighting factor. A weighting factor is set for each endpoint.

4. Endpoint method (type 2) – the value obtained by multiplying the characterisation factor of the endpoint by the inventory data is multiplied by a weighting factor.

$$I_4 = \sum_{\text{Impact}} \sum_{\text{Endpoint}} \sum_{X} \left(\text{Inv}(X) \times \text{CF}^{\text{Impact}}(\text{Endpoint}, X) \times \text{WF}_4(\text{Endpoint}) \right)$$

(15.4)

I_4 indicates the result of valuation and WF_4 is the weighting factor of the endpoint (Endpoint). In this case, the result of valuation is obtained by multiplying the inventory data by the endpoint characterisation factor and then multiplying by the weighting factor. In contrast to the previous approaches to weighting, **no normalisation is performed** and the endpoint score is expressed in amount of damage to the endpoint. WF_4 is expressed as the value per unit of the amount of damage (e.g., willingness to pay; WTP). A weighting factor is set for each endpoint.

These calculation methods make it possible to consolidate diverse environmental impacts into a single index.

Table 15.1 summarises the features of the various weighting methods introduced in this chapter.

6 Weighting Methods

This section presents details of the characteristics of the weighting methods developed thus far, by following the classification made in the previous section.

6.1 *Proxy Method*

With the proxy method, the actual environmental impact is not assessed through an explicit characterisation, but the inventory flow is converted into some preselected index, which is taken to express the environmental impact as a proxy parameter. Examples include MIPS (Material Input Per Service; Schmidt-Bleek 1994), CED (Cumulative Energy Demand; VDI-Richtlinie 1997), TMR (Total Material Requirement; Wuppertal Institute 1996), Ecological Footprint (Wackernagel and Rees 1996), and CExD (Cumulative Exergy Demand; Finnveden and Östlund 1997; Bösch et al. 2007). These methods are based on the premise that assessment of the actual environmental impact is difficult. They are also based on the assumption that the chosen index, e.g. the amount of energy consumption or the total amount of

Table 15.1 Summary of existing weighting methods in LCIA

	Proxy method	Midpoint method	Endpoint method (type1)	Endpoint method (type2)
Existing studies	MIPS TMR CED Ecological footprint	Eco-indicator 95 EDIP Eco scarcity etc.	Eco-indicator 99 LIME ReCiPe	EPS ExternE LIME ReCiPe etc.
Advantages	Indices are easy to understand Physical indices can be used Calculations are relatively easy	Full compliance with ISO 14044 Characterization results are used Calculations of weighting factors are relatively easy	Permits weighting among small number of items (endpoints), which reduces burden on respondents Methodologies of social sciences can be used	Permits weighting among small number of items (endpoints), which reduces burden on respondents Methodologies of social sciences and economics can be used Can be used for cost-benefit analysis
Problems	Low compliance with ISO 14044 Environmental impacts are not assessed	Weighting is difficult because of the large number of environmental issues Weighting is difficult for general consumers; highly representative weighting factors are difficult to obtain	Normalisation is required; it is necessary to tell the normalised contents to respondents Number of existing studies is small A large-scale survey is required for obtaining highly representative results	Number of existing studies is small Discussions on ethical issues are necessary A large-scale survey is required for obtaining highly representative results

substances used, will serve as an acceptable proxy for the actual environmental impact. The proxy parameter of environmental impact applied by MIPS and TMR is the total amount of substances related to the raw materials used throughout the lifecycle of the subject product. The proxy parameter applied by CED is the total amount of energy consumed either directly or indirectly through the life cycle. For the Ecological Footprint, the area of land used directly or required to assimilate the CO_2-emission is used as the alternative indicator, and this method was applied for assessing the sustainability of contemporary society. For the Ecological Footprint, there are cases where it has actually been used as a macro index for assessing environmental impact on a countrywide or global level (Kitzes et al. 2007).

Advantages of proxy methods include that the simple concept of the method makes it easy for practitioners to understand and apply, and it is easy to develop a weighting factor. On the other hand, issues of those methods include the points that the actual environmental impact is not analysed or assessed, that because of this it is

impossible to verify the precision of the impact assessment results. They do not include the characterisation as a step and therefore are not compliant with ISO rules, and many findings that would be obtained through natural scientific analyses, such as the impact of global warming on temperature rise and human health, are not taken into account. Because of these issues, proxy methods are not used frequently for case studies of LCIA. They can be used for obtaining rough indicators of a country's or an organisation's environmental performance given that a chosen index is considered relevant for the purpose (e.g. ecological footprint).

6.2 Midpoint Method

In a midpoint-type impact assessment, the environmental impact is assessed for a range of different environmental problems, such as global warming, resulting in a profile of midpoint impact scores and then a single index is obtained through weighting among the problems. Representative methods include Eco-indicator 95 (Goedkoop 1995), EDIP (Hauschild and Wenzel 1998), and ones developed by Huppes et al. (1997), Walz et al. (1996), Lindeijer (1996), Nagata et al. (1995), Itsubo (2000), Matsuno et al. (1999), and Yasui (1998). The midpoint method uses the result of characterisation as the basis of integration, and therefore it is highly compliant with international standards. Its other advantages include the point that its integration concept is easy to understand and the development of the weighting factors themselves is relatively easy, depending on the choice of weighting principle.

Midpoint methods are largely divided according to the weighting principle they are based on, which is either a panel method and or a distance-to-target method. With panel methods, weighting factors for the midpoint impact categories are determined based on the level of importance assigned to each environmental problem by sampled subjects or a panel of experts. Nagata et al. (1995) directly asks the level of importance of impact categories to particular groups of respondents (including students, members of industrial associations, and people related to LCA). Yasui (1998) obtains weighting factors by asking respondents the length of the remaining period before the onset of a critical situation and the seriousness of the crisis in the impact categories. Huppes et al. (1997) calculates a factor for determining the weight of each impact category based on discussions by a panel of policymakers, while Walz (1996) and Lindeijer (1996) turn to panels of environmental specialists for the calculation. However, the panel approach is problematic: the task of comparing more than ten impact categories places an excessive burden on respondents; the statistical significance of weighting factors obtained from answers to questionnaires is not examined in many cases; and information provided to the respondents as the basis for weighting is limited, which limits the transparency of the obtained factors. Because of these shortcomings, researchers have not developed midpoint methods based on the panel method in recent years.

The distance-to-target (DtT) approach was applied in the Eco-scarcity method (Frischknecht et al. 2006), Eco-indicator 95 (Goedkoop 1995), EDIP (Hauschild and Wenzel 1998), and methods developed by Matsuno et al. (1999) and Itsubo (2000), respectively. The Eco-scarcity method was developed by Müller-Wenk for assessing the ecological balance of companies. Equation 15.5 is used for applying this method to assess the impact. With this method, the ratio between the actual level of each substance and its pre-determined desired level is calculated. The larger the difference between the two is, the greater the resulting Eco-scarcity score of the substance becomes and this is accentuated compared to other methods by the squaring of the ratio in the expression.

$$SI = \sum_S \left(Inv._S \times IF_S \right) = \sum_S \left(Inv._S \times \frac{N_S}{T_S{}^2} \right) = \sum_S \left(\frac{Inv._S}{N_S} \times \left(\frac{N_S}{T_S} \right)^2 \right) \quad (15.5)$$

The actual level (such as the environmental concentration of a substance) and desired level (such as the environmental standard) will vary depending on the location and local political priorities. Therefore, eco-scarcity methods compliant with the environmental standards, etc. have been developed in European countries. JEPIX (Miyazaki et al. 2003) is the Japanese equivalent of the Eco-scarcity method.

Because the Eco-scarcity method determines the weighting factor of each substance without a characterisation to calculate its environmental impacts, it is not classified as a midpoint-type assessment method in the strict sense.

Eco-indicator 95, which was developed by Goedkoop and co-workers, integrates the environmental impacts in Europe in ten impact categories. Equation 15.6 is applied for this method and other distance to target weighting methods like EDIP (Wenzel et al. 1997).

$$SI = \sum_{Impact} \left(\frac{CI^{Impact}}{NV^{Impact}} \times \frac{NV^{Impact}}{T^{Impact}} \right) = \sum_{Impact} \left(\frac{CI^{Impact}}{NV^{Impact}} \times W^{Impact} \right) \quad (15.6)$$

In this formula, SI is the single index (non-dimensional) and CI^{Impact}, NV^{Impact}, T^{Impact}, and W^{Impact} indicate the **characterisation result**, **normalisation value**, **target value**, and **weighting factor**, respectively, in the impact category (Impact). This method is the same as the Eco-scarcity method in the basic idea of obtaining the weighting factor based on the ratio between the desired flow and actual flow. However, it differs in that a characterisation is performed and the weighting factors are set for impact categories. To enable comparison among impact categories, the bias inherent in the different metrics of the impact categories is removed from the result of characterisation by normalisation, which is conducted as a preparation of weighting.

The DtT method is based on the assumption that the importance of an environmental impact is represented by the difference between the desired value and actual value. It attracted a great deal of attention especially in the latter half of the 1990s, when many DtT methods were suggested. One advantage is that the grounds for

weighting is easy to understand because the national environmental standard or emission-reduction level is used as the desired value. The desired value is set based on information authorised by the national government, etc., instead of being determined subjectively by individuals, so involvement of the practitioner's subjective view can be prevented, and generic weighting factors can be developed. Another advantage is that it permits weighting factors to be determined relatively easily because only two parameters – the desired flow and actual flow – are used for weighting. On the other hand, the method has problems from the standpoint that the results may differ greatly depending on how the desired value is determined. For example, the weighting factor for global warming will differ completely between a case where the Kyoto Protocol target is used as the desired value and one where a level that allows virtually no impact of global warming to be generated is used. The weighting factor for eutrophication may be the environmental standard set for each lake or a stricter standard, where the latter will increase the weighting factor considerably and it will be difficult to ensure consistency in the ideas behind the desired values of all impact categories.

Thus, there exist many potential desired values, from among which methodology developers may choose in order to find the ones they feel are most appropriate, these chosen values then determine the weighting factors. This means that weighting factors are determined in a highly arbitrary (meaning they can vary from user to user) and potentially biased manner. To avoid such arbitrariness as much as possible, discussion is needed for setting common targets in advance; but this discussion has not occurred and agreement has not yet been reached. For these reasons, there has been little development research concerning this method in recent years. Instead, the prevailing attitude has been to leave the final valuation step up to the users.

A critique raised against DtT weighting methods is that they are really not weighting methods but rather a sort of **normalisation method** where the targeted level of impact is used as the normalisation reference instead of the current level of impact, as seen in the first part of the expression in Eq. 15.7, where NV^{Impact} cancels out, leaving the characterisation result normalised by the target value:

$$SI = \sum_{Impact} \left(\frac{CI^{Impact}}{NV^{Impact}} \times \frac{NV^{Impact}}{T^{Impact}} \right) = \sum_{Impact} \left(\frac{CI^{Impact}}{T^{Impact}} \right) \qquad (15.7)$$

An inherent assumption is thus that the further away from the target, the worse, no matter which impact is studied – exceeding the target by 50 % is equally important for climate change and for acidification. With all targets inherently equally important to reach in a DtT approach, opponents criticise that an explicit weighting of the targets is missing (Finnveden 1997).

6.3   Endpoint Method

With an endpoint method, environmental impacts are integrated by weighting among the endpoints that are damaged by the modelled impacts. Advantages of methods classified as endpoint-type include:

– They make it possible to clearly distinguish between the specialised area based on natural scientific knowledge (until the damage assessment of the endpoint) and the specialised area based on social scientific analysis (from the endpoint until the single index),
– Transparency is improved by clarifying items to be included in the assessment (types of disease, types of species), and
– Burden on respondents is small because the number of items to compare is small.

  On the other hand, the following problems are included:

– Studies for assessing the amount of damage to the endpoints, which become the premises of integration, have yet to be mature, because of which a large amount of work is required for developing assessment methods.
– The assessable range (substances or endpoints) may be limited.

  Endpoint methods are divided into methods where normalised midpoint scores are weighted among endpoints (type 1) and methods where weighting is performed by multiplying the value per unit of damage to the endpoint by the result of endpoint characterisation (type 2).

6.3.1   Endpoint Method (Type 1)

With the endpoint method (type 1), specialists, general consumers, etc. determine the values of environmental impacts in questionnaires or through group discussions. With Eco-indicator 99 (Goedkoop and Spriensma 1999), weighting among three predefined endpoints (human health, ecosystem quality, and resources) was performed by LCA specialists. Table 15.2 shows the weighting factors obtained with the method.
  Normalisation was performed in a way that allowed the sum of the weighting factors to be 1. Because the number of endpoints for weighting is limited to three,

Table 15.2 Rounded weighting factors per cultural perspective in Eco-indicator 99 (Goedkoop and Spriensma 1999)

	Average (%)	Individualist (n = 10) (%)	Egalitarian (n = 14) (%)	Hierarchist (n = 5) (%)
Ecosystem quality	40	25	50	40
Human health	40	55	30	30
Resources	20	20	20	30

Table 15.3 Weighting factors of LIME1 and LIME2

	LIME1 (N = 400, Kanto region)	LIME2 (N = 1,000, Japan)
Human health	0.31	0.28
Social assets	0.21	0.15
Biodiversity	0.26	0.36
Primary productivity	0.23	0.21

the burden on the respondents is relatively small. This method is further characterised by the point that weighting is undertaken for each of three perspectives or lines of environmental thought (hierarchist, egalitarian, and individualist). This permits the practitioner to make analysis based on his or her own environmental thinking by determining the group to which subjects belong. On the other hand, the number of samples from which the weighting factors are determined is small, and therefore the weighting factors lack representation, which makes this method unsuitable for general use.

For LIME (Itsubo and Inaba 2005, 2012), weighting factors were calculated for comparison among four endpoint items (human health, social assets, biodiversity, and primary productivity). The first version based the factors on interviews with 400 people from the Kanto region, but the latest version, LIME2, is aimed at obtaining factors that represent the environmental thinking of the Japanese people, and interviews of 1,000 general consumers, who were selected by applying the random sampling method, were conducted for that purpose. Dimensionless weighting factors were obtained by multiplying the result of conjoint analysis (willingness to pay per unit of damage) by the **normalisation value**. (Explanations about willingness to pay per unit of damage are given in the next section.) Table 15.3 shows weighting factors of LIME1 and LIME2.

Here again, the weighting factors were scaled to give sum up to 1. The number of samples is smaller for LIME1 than for LIME2 and the areas surveyed for LIME1 are limited to particular regions. Thus, the respondents differ between these two surveys, and direct comparison between them is impossible. As the table shows, the items weighted relatively heavily are human health in LIME1 and biodiversity in LIME2. The method of calculating these values is explained in the next section.

6.3.2 Endpoint Method (Type 2)

With this method, the result of integration is obtained by calculating the value per unit of damage to an endpoint and multiplying the value thus obtained by the result of characterisation. EPS, ExternE, and LIME are classified as belonging to this approach. In all of these, the economic value per unit of endpoint is calculated and results of assessments made by using these methods are expressed in economic metrics. Much effort in environmental economics has been put into translation of environmental impact into economic value.
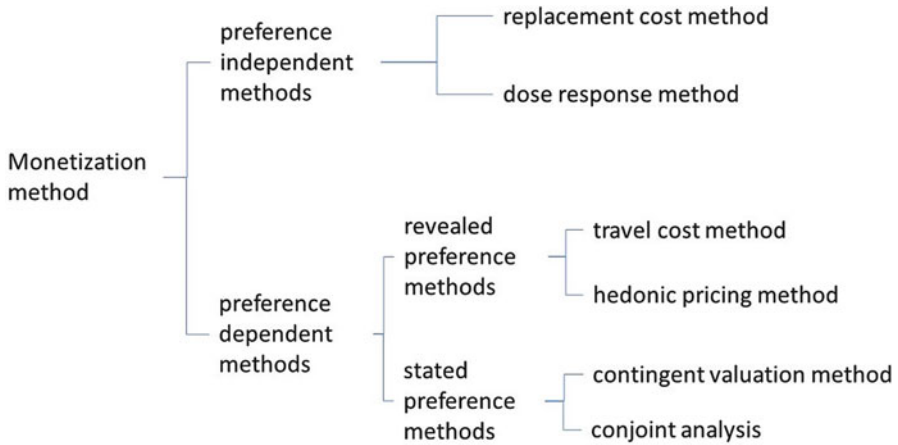
Fig. 15.3 Classification of assessment methods based on environmental economics

Using economic assessment means that the results are expressed in monetary values. This not only makes the results easy to understand and communicate but also allows them to be applied for cost-effectiveness analysis, for example. On the other hand, methods for converting environmental impacts resulting in health damage and ecosystem decline into economic values are still in the development phase, and results may be strongly biased or incomplete and their use often inappropriate depending on how the information is conveyed. It has also been pointed out that conversion of people's health, etc. into economic value is ethically problematic, which is another issue regarding this method.

The assessment methods based on environmental economics are classified mainly as shown in Fig. 15.3. First classification goes on whether environmental value is assessed independently from individual preferences (preference-independent methods) or based on individual preferences (preference-dependent methods).

Preference-independent methods include replacement cost methods and dose–response methods. A replacement cost method is an approach with which an environmental value is substituted by the cost needed for producing a substitute for the subject environment. For example, if the water-retaining function of a forest is lost due to e.g. clearing of the forest, it could be provided by the building of a dam. The cost for constructing and maintaining the dam is then regarded as the value of the forest's water-retaining function. Other examples in this vein could be the use of repair or mitigation costs associated with cleaning a pollution that has occurred to bring the environment back to the state it had before the impact was caused. With a dose–response approach, if any monetary value is created by deteriorating an environment this value is regarded as the value of the lost environment. Weidema applied annual income as the value of avoidance of the loss of one life-year (Weidema 2009). Preference-independent methods excel in that the

calculations are relatively easy to perform, but the replacement cost methods are strongly dependent on the chosen technological solution. Furthermore, the dose–response methods mean that if no value is generated by damaging the environment, then the resulting damage has no value. These problems with the above approaches make their societal acceptance difficult. Currently, there are few cases in which a preference-independent method is used.

Preference-dependent methods are divided into the revealed preference method and the stated preference method. The former are applied for assessing the individual preferences on the environment indirectly based on the actual amount of money spent by individuals, while with the latter methods environmental values are assessed based on individual preferences revealed by asking the individuals directly. The revealed preference methods include the travel cost method and hedonic pricing method. With the travel cost method the value of the subject environment is assessed based on the expenses people incur in visiting the subject site. The hedonic pricing method is used to assess values of various living environments based on real estate prices, including those of land and houses. The advantage of these methods is that the results are highly reliable because values found for different individuals are estimated by the amount of money they actually spent. On the other hand, a problem with these methods is that subjects of the assessment are limited to fields where application of individuals' payment behaviour can be observed as compensatory behaviour, so these methods are restricted in scope, and accordingly, there are few cases where they have been used for weighting in LCA.

Stated preference methods excel in that they permit measuring not only of use values but also non-use values such as bequest value and existence value. Therefore, in many cases these days these methods are used for assessments based on environmental economics. Typical methods that fall into the stated preference methods include the contingent valuation method (CVM) and conjoint analysis. CVM is an approach where the value of a certain environment is measured by directly asking people related to the environment how much they would be willing to pay for the said ecosystem or environmental service (willingness to pay, WTP) or how much they would be willing to accept to give up the ecosystem or environmental service (willingness to accept, WTA), making estimates based on the distribution of the answers, and extrapolating the results to the entire relevant population. This is the most widely used method for assessing values of ecosystems including existence value because it is highly flexible, allowing assessors to tell their respondents the characteristics of the subject environment by using the questionnaire forms they prepare in advance. Diverse creative measures are applied for obtaining respondents' true willingness to pay, and there exist guidelines on how to make questionnaire forms (Arrow et al. 1993). CVM has been used for a variety of subjects. In the United States, it is used to provide bases for calculations of compensation costs in court procedures, for example. In this way, assessments made with CVM are introduced in the real world for purposes other than cost-benefit analyses. With regard to LCIA, endpoint values converted into monetary values with CVM are applied for integration with ExternE and EPS.

Conjoint analysis is similar to CVM in that individuals are directly asked about their intentions. However, it greatly differs from CVM in that it not only integrates the environment as a whole but also enables identification of differences in the strength of people's preferences among various attributes of the subject environment. If a natural environment is regarded as a single attribute, CVM is the method to be used. However, there are often cases where a natural environment should be regarded as having multiple attributes. For example, when the value of a tideland is measured, analysis made in consideration of tradeoffs among various factors (attributes) such as the natural landscape, protection of species, and cost for conserving the tideland may be advantageous for finding the direction of policy decision-making. Advantages of conjoint analysis are exerted in such a case. With regard to LCIA, conjoint analysis has been used for development of weighting factors in LIME.

7   Examples of Midpoint Methods

As part of the EDIP midpoint LCIA methodology, a weighting step was developed relying on political reduction targets and applying a distance-to-target approach. For each of the midpoint impact categories covered by the EDIP methodology weighting factors were calculated by

1. Identifying politically set reduction targets for elementary flows that contribute to the impact category. Only stated and binding targets set e.g. as part of an international treaty or national action plan are considered.
2. Harmonising the reduction targets to a common format across impact categories. Politically set targets are typically stated as a targeted reduction in the emission level in the reference year that must be attained in the target year. Target years and reference years differ between agreements and elementary flows, and a harmonisation is therefore performed by linear inter- or extrapolation to represent the corresponding reduction over a 10 year period.
3. Application of the harmonised reduction targets to the inventory of society's current emissions, which in EDIP is also used for calculation of the normalisation reference, to arrive at the inventory of targeted annual emissions.
4. Characterisation of the targeted annual emission inventory, applying the EDIP characterisation factors, to arrive at the targeted level of impact after 10 years in accordance with the political reduction targets. Both the current level of impact applied in the normalisation, and the targeted level of impact calculated for the weighting, are expressed on a per capita basis as current and targeted Person Equivalents respectively.
5. Calculation of the weighting factor as the current level of impact (the normalisation reference) divided by the targeted level of impact after 10 years

Table 15.4 Midpoint weighting factors of the EDIP methodology based on distance to politically set environmental targets

Impact category	Weighting factor
Global warming	1.3
Ozone depletion	23
Photochemical ozone formation	1.2
Acidification	1.3
Nutrient enrichment	1.2
Human toxicity	2.8
Ecotoxicity	2.3

Excerpt from Wenzel et al. 1997

$$
\begin{aligned}
Weighting\ factor &= \frac{Current\ level\ of\ impact\ in\ reference\ year}{Targeted\ level\ of\ impact\ ten\ years\ after\ reference\ year} \\
&= \frac{Person\ Equivalent\ in\ reference\ year}{Targeted\ Person\ Equivalent\ ten\ years\ after\ reference\ year}
\end{aligned}
\tag{15.8}
$$

Table 15.4 shows an excerpt of EDIP weighting factors.

When applying these weighting factors to the normalised impact scores, the impacts of the product system are expressed in the metric of targeted person equivalents:

$$
\begin{aligned}
Weighted\ impact\ score &= Weighting\ factor \cdot normalised\ impact\ score \\
&= \frac{Person\ Equivalent\ in\ reference\ year}{Targeted\ Person\ Equivalent\ ten\ years\ after\ reference\ year} \\
&\quad \cdot \frac{Characterised\ impact\ score\ of\ product\ system}{Person\ Equivalent\ in\ reference\ year} \\
&= \frac{Characterised\ impact\ score\ of\ product\ system}{Targeted\ Person\ Equivalent\ ten\ years\ after\ reference\ year}
\end{aligned}
\tag{15.9}
$$

The weighting using EDIP's distance to target weighting factors may thus also be seen as a normalisation using the targeted level of impact as reference information.

As visible from Table 15.4, the weighting factors based on political reduction targets show a modest variation across the impact categories (apart from ozone depletion where a nearly complete phase out of the contributing elementary flows was the target).

As an alternative to political targets, EDIP also investigated the use of environmental carrying capacity or sustainability targets for calculation of weighting factors. With these targets the resulting person equivalents represent the environmental space that is available on average to each of us in a sustainable society or a

society that respects nature's carrying capacities. They are generally far below the politically based targeted person equivalents and show a considerably larger variation in the weight put on the different midpoint categories, but they are also more uncertain due to the ambiguity of the setting of carrying capacities and sustainability targets (Hauschild and Wenzel 1998).

8   Examples of Endpoint Methods

ExternE applies a method called impact pathway analysis. With this method, as with the endpoint-type methods, monetary value of the environmental impact is obtained by estimating the amount of potential damage on endpoints and multiplying the estimated value by WTP per unit of amount of damage. Endpoints are subdivided into death, disorders, and others, and the monetary value is set for each of the subdivided cases. Different methods are applied for different WTP endpoints. For example, with regard to death, WTP for reduction of health risk was calculated with CVM for subjects from multiple countries, and the value thus obtained was converted into WTP for one life year. As a result, a value of life year (VOLY) at 50,000 euro/year was obtained. Concerning disorders, WTP per case was set for each level of severity. The value for disorders was obtained from the sum of (1) the resource cost including insurance cost and cost of treatment at hospital, etc., (2) the opportunity cost including productivity lowered by reduction of work hours, and (3) disutility including nuisance and pain. In addition to these, weighting factors related to noise, view, cultural heritage, buildings, ecosystems, and crops were also defined. Table 15.5 shows major weighting factors obtained with the method.

In addition to the values for endpoints shown in Table 15.5, the ExternE report shows integration factors for LCA obtained by multiplying these values by the amount of damages. For example, where 1 kg of PM2.5 is emitted by road traffic in a suburb, the average value is 15.2 €/kg. Here, uncertainty analysis was made and confidence intervals also shown.

Table 15.5 Different ways of determining WTP per unit of endpoint by applying ExternE

Endpoint	Approach	Value (€) per unit
Death	Contingent valuation method	50,000 per VOLY
Morbidity	Resource cost + opportunity cost + disutility	2,000 per admission (hospital admission), 670 per case (emergency room visit for respiratory illness)
Cultural and historical heritage	Expenditures for renovation of historical buildings	
Crop loss	Prices	Prices per ton of each crop
Ecosystem	Abatement costs	WTP per hectare protected ecosystem

Table 15.6 Examples of weighting factors of EPS method (Steen 1999)

Category	Unit	WF (Euro)
Life expectancy	Person-years	85,000
Severe morbidity	Person-years	100,000
Morbidity	Person-years	10,000
Severe nuisance	Person-years	10,000
Nuisance	Person-years	100

With this method, WTP per case of disorder was determined by type, such as hospitalisation and use of an emergency room. It differs from LIME and Eco-indicator 99 in that conversions to monetary values are made without consolidation to the Area of Protection (AoP). Therefore, in the strict sense, weighting among AoPs was not conducted. For setting monetary values, the method applies different approaches for different endpoints by quoting results obtained with CVM for the impact on health while applying abatement cost concerning the impact on ecosystem, for example. Discussions are needed for determining whether or not the weighted results can be summed up because conditions for integration, groups of respondents, and period when the survey was made differ among the endpoints.

With the EPS method, four endpoints – human health, production capacity of ecosystem, non-biological resources, and biodiversity – were set, and then a weighting factor was defined for each of five types such as death and disorder for human health, each of five types including crops, fish, and irrigation water for production capacity of ecosystem, each type of resource such as oil, coal, and iron for non-biological resources, and one type for biodiversity. Table 15.6 shows examples of the weighting factors thus defined. In the case of impact on health, the weighting factor per case differs greatly depending on the severity of the disorder. For example, the weighting factor concerning death was obtained by using the value for Value of Statistical Life (VSL) of ExternE.

As for ExternE, endpoints that have yet to be consolidated into AoPs, such as human health and production capacity, are converted into economic indices with EPS, and therefore weighting among AoPs in the strict sense of the term was not conducted.

For LIME, conjoint analysis was used to develop weighting factors concerning four types of AoP. Economic value for the amount of damage per unit of each AoP was calculated by statistical analysis such as logit model and random parameter logit model. The results are shown in Table 15.7 below.

This method differs from ExternE and EPS in that values are given only to four types of AoPs. Respondents were asked to choose from the hypothetical profiles including four types of environmental attributes and monetary attribute. Their choices are analysed to obtain WTP for avoidance of a unit of damage on each AoP such as biodiversity. LIME2, the latest version, is characterised by the point that highly representative weighting factors were obtained from results of a survey of 1,000 households. On the other hand, it must be noted that LIME2 does not reflect environmental thinking of other countries with different cultures and different economic situations.

Table 15.7 Weighting factors estimating external cost in LIME1 and LIME2

AoP	Unit	LIME1 (N = 400, Kanto region)	LIME2 (N = 1,000, Japan)
Human health	1 DALY	1.42E + 7	9.70E + 6
Social assets	10,000 yen	1.00E + 4	1.00E + 4
Primary productivity	1 ton	3.78E + 4	2.02E + 4
Biodiversity	1 species	1.27E + 13	4.80E + 12

9 Comparison Between Endpoint-Type Methods and Research Needs

Table 15.8 shows a comparison of endpoint-type weighting methods. All of these methods share the same assessment framework but differ on various points, such as assessment objects in terms of substances or impact categories. Important differences and future problems concerning weighting methods are described below.

9.1 Area of Protection and Damage Indicators

All of the above methods define human health as an AoP. However, though the ecosystem is commonly included in the objects of assessment, the methods differ in what part of the ecosystem should receive attention. The object of EPS is the degree of contribution (ratio) to extinction of species in a year, while that of Eco-indicator 99 is the ratio of vanished species (vascular plant species) and LIME uses the expected number of extinct species.

The methods also differ in how to consider the impact on human society, such as resources, materials, and agricultural products. LIME has established 'social assets' as a concept comprehensively covering what is treated as valuable things in human society (non-biological resources, agricultural products, marine resources, and forest resources). In addition to this, EPS includes cations, which is used as a buffer for soil acidification, and divides AoPs into resources and production capacity. Eco-indicator 99 does not include agricultural products or marine resources in the AoP, but includes resources, limited to mineral resources and fossil fuels. ExternE includes cultural properties, materials, and agricultural products for calculations, but has no clear definition of the area of protection.

LIME and EPS include the impact on primary production (plant production) in the objects of calculation, whereas Eco-indicator 99 and ExternE do not. In addition, though LIME defines 'primary production' as an area of protection, EPS considers it a part of the 'production capacity of the ecosystem'. Therefore, the two methods differ in their range of AoP.

Table 15.8 Comparison among five endpoint methods of integration of environmental impacts

Method	EPS	ExternE	Eco indicator'99	ReCiPe	LIME2
Country of development, year of publication	Sweden (Revised in 2000)	EC (Revised in 2005)	Netherlands (Revised in 2000)	Netherlands	Japan (2008)
Assessable steps	Weighting, integration	Weighting, integration	Damage assessment, normalisation, weighting, integration	Characterisation, damage assessment, weighting, integration	Characterisation, damage assessment, weighting, integration
Region subject to impact assessment	Sweden	Europe	Europe	Europe	Japan
AoP and damage index	Human health	YOLL, etc.	No definition (Damage to human health, ecosystem, and materials are taken into account)	Human health	DALY
AoP and damage index Impact categories	Biodiversity — NEX (ratio to extinction of species)	No definition (Damage to human health, ecosystem, and materials are taken into account)	Quality of ecosystem — PDF (Ratio of disappeared species)	Human health — DALY	Human health — DALY
	Production capacity — kg	10 categories including resources, global warming, ozone depletion, and carcinogenic substances	Quality of ecosystem Resources — PDF (Ratio of disappeared species) Excess energy	Quality of ecosystem — PDF (Ratio of disappeared species)	Biodiversity — EINES (increase in number of extinct species)
	Resources — Amount of money		Resources — 18 impact categories	Resources — Surplus cost (€)	Primary production — tons
	Sensuousness — Not measured		Excess energy — 15 categories including global warming, ozone depletion, and urban area air pollution		Social assets — Damage cost (yen)
	The above five items have been defined as impact categories. — Air pollution, global warming				

Table 15.8 (continued)

Method	EPS	ExternE	Eco indicator'99	ReCiPe	LIME2
Assessment process	Inventory → category endpoint → single index	Inventory → category endpoint → single index	Inventory → area of protection → normalisation → single index	Inventory → midpoint → area of protection → normalisation → single index	Inventory → characterisation → category endpoint → area of protection → single index
Weighting method	Market value where it exists, otherwise citation from CVM, etc.	Market value where it exists, otherwise citation from CVM, etc.	Panel method	Panel method, damage cost, prevention cost	Conjoint analysis
Unit of single index	Damage cost	Damage cost	Non-dimensional index (3 types: hierarchist, egalitarian, individualist)	Non-dimensional index, damage cost, prevention cost	Damage cost, non-dimensional index
Number of samples for weighting survey and survey method	Citation only; no field survey	Unknown	80 people (collection rate: 20 %), mail survey	Panel weighting, citation from literatures (damage cost, prevention cost)	1,000 households (collection rate: 48 %), visiting interview survey

9.2 Methods of Indicating Weighting and Integration Result

Approaches to weighting can be roughly divided into economic assessment methods (ExternE, EPS, LIME2) and panel methods (Eco-indicator 99). The integration result is expressed in amount of money (Euro or Yen) under the former methods, whereas it is expressed in a non-dimensional index under the latter. An advantage of expressing the environmental impact in an amount of money is that the results are easy to interpret, and therefore can be compared with costs or used for cost-benefit analyses, for example. However, indicating human health or the ecosystem in economic value involves an ethical problem. Indicated values for developed countries may also be higher than those of developing countries, which is another problem pertaining to the economic assessment methods. Expression in a non-dimensional index will reduce these problems but will make results difficult to understand for general consumers and policy decision-makers, which limits their external use.

9.3 Individual Differences and Variation of Weighting

Weighting differs among individuals. It would be important to express such differences as a range of weighting factors. ExternE shows the range of integration factors for each substance, but it is unknown where there is uncertainty of the amount of damage or variation in weighting. Eco-indicator 99 does not show variation in weighting factors but sets a weighting factor for each type of cultural perspective. LIME2 expresses individual differences in weighting quantitatively through an analysis that uses the random parameter logit model (Itsubo et al. 2012), showing that individuals constituting a group differ in value judgment but have a certain distribution. It is desirable for ensuring transparency of weighting factors to show the level of variation of weighting factors as an indicator of individual differences in value judgment.

The result of weighting is subject to influences of various factors such as culture, income, age, gender, religion, and educational background. Currently, there has been no study that looks at how much influence is given to weighting by differences in these factors.

9.4 Representativeness of Weighting Factors

Many of the methods shown above were developed based on the assumption they would be used for general purposes, regardless of what the products are and who the users are. Accordingly, they require confirmation that the value judgment represents the relevant population. CVM and conjoint analysis, which are normally used

in environmental economics and other fields, are based on a merger between economics and inferential statistics. With inferential statistics, a statistical model is applied to a result of a survey of samples selected from a specific population by applying the random sampling method, and social preferences of the population are inferred through mathematical analysis. Results of the inference are verified for determining whether or not they are statistically significant. It is also verified whether or not the statistical model used for the regression to the population represents the social preferences of the population. Only results that pass these verifications may be used for general purposes. Eco-indicator 99 is based on weighting by environmental specialists in Europe. The number of samples is small and their representativeness is unclear. With regard to CVM applied in ExternE and EPS, it is unknown whether or not multiple results of CVM were obtained from the same group of respondents. LIME represents Japanese people's views but cannot be used for weighting in other countries.

Most of the existing methods calculate their weighting factors with the preferences of current generation, because their responses to questionnaire would be analysed. None of the weighting factor systems considers the preferences or interests of future generations, although weighting would be changed by time transition. Only ExternE method took into account discount rate in their monetisation.

As described above, existing methods of weighting differ in diverse points and leave a number of problems. Research and development for improving the problems while making use of the advantages of these methods will be required in the future.

10   Outlook

Integrating a wide range of environmental impacts means allocating weights to midpoint impact categories or to the objects that receive impacts of environmental changes, such as human health, biodiversity, agricultural products, and marine products industry, regardless of whether or not they are explicitly shown. Results of such comparisons cannot be obtained from knowledge based on natural science but are determined by subjective views of the assessors or practitioners or by how the given group views the environment. How people value the environment differs according to their social background, such as cultural background, educational background, and economic conditions. Methods of integration suggested thus far differ in the population subject to weighting (e.g., population in Europe or Japan), and therefore results of LCA are often inconsistent with each other due to the integration methods applied. In addition, even when the population subject to weighting is identical, use of different integration methods may lead to different conclusions (Itsubo 2000).

This leads to a concern over abuses of weighting, such as: manipulating weighting factors in a way that the assessment results of a company's products

will be better than those of its competitors', and only disclosing results obtained by using assessment methods that are advantageous for a company's products. To restrict such abuses, ISO 14044 positions weighting as an optional element and prohibits its use in comparative assertions disclosed to the public.

Among practitioners some have negative attitudes towards the practice of weighting and integration because of the above reasons. However, a substantial number of companies make use of integration by placing greater emphasis on the positive features of integration, that is, easy-to-understand assessment results and the wide range of application, based on the recognition that integration comes into effect on the premise of ethical, social, and economical elements. Many pioneering companies make assessments in support of corporate evaluation, environmental accounting, and environmental efficiency assessments by using their own weighting factors or existing ones, and disclose the results in their environmental reports or on their websites. These are examples of using integration indices as tools for communication.

More companies may in the future use integration by making use of its advantages, that is, ease of interpretation and high applicability of assessment results. For this to happen, there is an urgent need to develop an integration method that can be used for such general purposes.

11   Conclusions

This chapter presents the different features of weighting and integration approaches applied in LCIA. Methods of weighting are classified into proxy methods, midpoint methods, and endpoint methods. **With an endpoint method**, **weighting is conducted after normalisation**, **or values for results of characterisation are multiplied without normalisation**.

An advantage of a **proxy method** is that assessment results are easy to understand because physical quantities such as weight and energy are used. On the other hand, this method has problems such as incompliance with the ISO standard's requirement that a characterisation be performed as part of the impact assessment, and the point that the environmental impacts are not assessed directly.

Advantages of a **midpoint method** include compliance with the ISO framework and the point that it permits weighting that uses characterisation results. On the other hand, it has problems such as that weighting is difficult because of the large number of impact categories and that it is difficult with the DtT method to set desired values that are truly equivalent among all impact categories.

Advantages of an **endpoint method** include the points that allocating weights to areas of protection rather than midpoints reduces the number of subject items and therefore reduces burden on respondents, and that furthermore it permits use of an assessment method of environmental economics. On the other hand, problems of this method include the limited number of studies conducted thus far and the need for a large-scale interview survey, which is costly.

In this way, advantages and problems differ among approaches. In recent years, however, weighting with the endpoint-type methods has been attracting attention due to the advancement of characterisation methodologies of this type.

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