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LIME2

Life-cycle Impact assessment Method based on Endpoint modeling

Chapter 0 - Introduction

LIME2

Life-cycle Impact assessment Method based on Endpoint modeling

Introduction

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Introduction

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Introduction

Social Backgrounds and Research Trends

- Number of registrations for ISO14001 examination: 22,527 (Jan. 2007) (Ministry of the Environment 2007)
- Number of companies that issued environment reports and CSR reports: 933 (2005)[*1] (Ministry of the Environment 2007)
- Number of companies that conducted environmental accounting: 790 (2005) (Ministry of the Environment 2007)
- Number of commodities for which ecomark was certified: 4,726; number of certified companies: 1,665 (Sep. 2007) (Japan Environment Association 2007a)
- Number of products registered for the environmental label type III (EcoLeaf): 471 (Mar. 2008) (Japan Environmental Management Association for Industry 2008)
- Number of companies that participated in Eco-Products Exhibition: 600[*2]; number of visitors: 164, 903 (Dec. 2007) (Eco-Products 2007 Secretariat 2008)
- Companies implementing or considering implementing LCA: 41% of listed companies, 24% of unlisted companies – 32% on average (Ministry of the Environment 2005)

As shown above, many companies have disclosed results of environmental activities in various ways. This indicates that, because of social recognition of the construction of sustainable society as the largest challenge in this century, many business entrepreneurs consider social contribution through environmental activities to be essential for continuing their businesses.

Environmental activities carried out under the strong leadership of managers must be reported to society, such as consumers and business partners. However, it is difficult to convey the results of companies' environmental activities. For example, if companies carry out activities for reducing the emission of CO_2 or NOx or the amount of waste and actually reduce environmental burden, they cannot express it in a way easy for consumers to understand, such as resultant relaxation of temperature rise or increase in space for disposal. Most recipients of information are general consumers and business partners, not environmental experts. Although companies spend a lot of costs for environmental activities to fulfill corporate social responsibility (CSR), such activities might not be evaluated properly if the resultant effects are not conveyed accurately.

Externally provided information on developed environmental-friendly products and

[*1] About 30% of the companies that gave valid responses (about 60% in the case of listed companies) issued environment reports.
[*2] Of the companies that participated in the Eco-Products Exhibition, about 30% have carried out LCA (Itsubo et al. 2007).

corporate environmental activities must be easy for everyone to understand. Because qualitative expression is not sufficiently persuasive, tools and methods for quantitative assessment are needed.

LIME was developed as a method for supporting LCA and other environment assessment tools smoothly and with high precision. LIME has been used in various fields since the publication of the first version (hereinafter referred to as "LIME1"). This chapter first describes the development of LCIA research and trends in the use of LIME.

0.1 International trends in LCIA research

Since LCIA drew international attention as the main step of LCA, the methodology and the use have been developed actively.[*3] This section examines the development of LCIA so far. Table 0.1-1 shows comparison between LCIA trends overseas and in Japan.

Table 0.1-1: Development of LCA and LCIA overseas and in Japan

Year	Overseas	Japan
1980s	Concepts of corporate management focusing on the environment, such as corporate eco-balance, were introduced.	Mainly, energy analysis
1989	SETAC held workshops on LCA. Since then, Europe SETAC has held regular meetings for presentation of LCA researches.	-
1990	The eco-scarcity method (Ahbe et al. 1990) was published and drew attention as the forerunner of the DtT method.	-
1992	CML published an LCA guide (Heijungs et al. 1992) and proposed main characterization factors.	Yoshioka et al. (1992) published an environment analysis method that uses the input-output table.
	EPS was published (Steen et al. 1992) and drew attention as an economic assessment method for LCIA.	
1993	SETAC published the Code of Practice (Consoli et al. 1993), which contributed to the firm establishment of LCA framework.	Japan participated in ISO's preparation of LCA international standards.
	ISO began discussions about preparation of LCA guidelines.	Concrete examples of inventory analysis were published.
	Wuppertal Research Center proposed alternative indexes for environmental impact (Schmitd-bleek 1993). The concept of factor was spread over the world.	Chemical Economy Research Institute (1993) published an energy analysis research report concerning basic materials.
	The eco-scarcity method was revised (Braunschweig 1993).	Plastic Waste Management Institute (1993) published LCI data on plastic.
1994	Europe SETAC arranged the methodology of LCIA (Udo de Haes, et al. 1994). The relation with risk assessment was strengthened.	The 1st International Conference on EcoBalance was held. Domestic LCA research began in earnest.
1995	Eco-indicator 95 was published (Goedkoop 1995). This promoted proposal of many DtT methods.	LCA Japan Forum was established. The necessity for LCA infrastructure was

[*3] LCIA is one step of LCA. For the characteristics of LCA and trends in the use of it, see "0.1.1 LCA.")

Year	Overseas	Japan
		commonly recognized.
	ExternE was published (EC 1995). External assessment of power plants was conducted.	Nagata et al. (1995) proposed an integration method that uses questionnaires
	Nordic Guideline (Lindfors et al. 1995a, 1995b) was published and drew attention as guidelines LCA and LCIA.	National Institute for Resources and Environment developed LCA software NIRE-LCA
		Japan Environmental Management Association for Industry (1995) conducted LCI for refrigerators.
		National Research Institute for Materials and the Society of Non-Traditional Technology (1995) prepared inventory data about metal materials.
1996	SETAC established a working group of LCIA experts and published a document about the current situation of LCIA research (Udo de Haes 1996).	The 2nd International Conference on EcoBalance was held.
	Ecological footprint (Wackernagel 1996) was proposed. The concept of environmental capacity drew attention.	
	EPA summarized the significance of LCA and ways of use of LCA (Curran 1996).	
	Guinée et al. (1996) developed characterization factors by the use of USES, a fate analysis method for chemical substances.	
	UNEP (1996) disclosed a document that summarized the current situation of LCA and ways of use of LCA.	
1997	The international standards of ISO 14040 (1997) were published, and the framework of LCA was established.	JIS Q 14040 (1997) was published. Domestic standards were established according to ISO.
	CED (cumulative energy demand) was proposed as an alternative index for environmental impact (VDI-Richtlinien 1997).	LCA Forum issued a report that summarized the domestic situation of LCA. Proposals specified therein became bases for LCA Project.
	The importance of regional assessment of environmental impact was pointed out (Krewitt et al. 1999, Potting et al. 1997, Huijbregts 2000).	
	The importance of introduction of damage assessment for the objects of protection into LCIA was pointed out (Müller-Wenk 1997). Loss of life expectancy and others were mentioned as useful damage indexes.	Matsuzaki et al. (1997) developed the Japanese version of USES and calculated the characterization factors of toxic chemicals.
	The development of Eco-indicator that shifted to endpoint modeling began (Goedkoop 1997)	
1998	Denmark announced the Environmental Design of Industrial Products (EDIP) for LCIA as a result of a national project (Hauschild et al. 1998).	The Environment Agency issued “Guidelines for Life Cycle Inventory Analysis” and introduced case studies on beverage containers
	A damage assessment method for health impact by the use of DALY as a damage index was proposed (Hofstetter 1998). Assessment factors were categorized based on environmental ideas.	LCA Project (Ministry of Economy, NEDO, JEMAI) started. A data provision system by the use of LCI database and web base was developed. At the same time, the development of LIME started.
	A revised version of ExternE was published (Holland et al. 1998). Assessment of heavy metal and ozone and	Yasui (1998) proposed the time consumption method.

Year	Overseas	Japan
	assessment of uncertainty were added.	Development of a LCIA method with consideration for environmental conditions in Japan drew attention (Moriguchi 2000, Matsuno et al. 1999, Itsubo 1998, 1999)
1999	SETAC LCIA Working Group issued a document that summarized trends in research on LCIA (Udo de Haes et al. 1999).	
	Eco-indicator 99 was published (Goedkoop et al. 1999). An integration method based on endpoint modeling. Development of research on damage assessment became active.	
	EPS version 2000 was issued (Steen 1999). Revised version of the economic assessment method based on endpoint modeling.	
	Development of a method for assessment of damage from noise was attempted (Müller-Wenk 1999).	
2000	International standards of ISO 14042 (2000) were issued as a result of long-term discussions.	At the 4th International Conference on EcoBalance, many participants presented results of discussions for development of damage functions.
	Development of an LCIA method for land use and biodiversity drew attention (Kollner 2000, Lindeijer 2000, Meent 1999, etc.)	Research Group for Comparison among Containers (2000) conducted LCA for packaging containers. The time consumption method was used for LCIA.
	Discussions about the relation between damage assessment and characterization became active. EPA held a workshop to discuss the characteristics of both.	
2001	CML published a revised version of LCA Guide (Guinée et al. 2001), which explained both damage assessment and characterization. LCM that used LCA for corporate management drew attention, and 1st International Conference on LCM was held.	
2002	UNEP/SETAC Life Cycle Initiative was inaugurated. Three groups (LCI, LCIA, LCM) were established.	Environmental efficiency and environmental accounting drew attention, and LCIA method began to be used for them.
	Discussions for fusion between damage assessment and characterization began in Holland (Goedkoop et al. 2002).	At the 5th International Conference on EcoBalance, a presentation was made about framework of a method based on endpoint modeling and damage assessment (Inaba et al. 2002, Nakagawa et al. 2002, Hayashi et al. 2002, Itaoka et al. 2002, Nagata et al. 2002, Hirosaki et al. 2002, Uchida et al. 2002, Itsubo et al. 2002).
	EPA announced LCIA method TRACI (Bare 2002), a characterization method suitable for environmental conditions in the US.	AIST (2002a, 2002b, 2002c, 2003a, 2003b) held workshops on the LCIA method five times.
2003	IMPACT 2002 (Jolliet et al. 2003) was published. Methodology was created, focusing on characterization and damage assessment.	The list of factors for LIME1 was published at the end of LCA Project (Japan Environmental Management Association for Industry 2003).
	A revised version of EDIP (Potting 2003) was published. Attention was paid to a characterization method at the local level, and the list of factors by country was shown.	Discussions were held to apply conjoint analysis to LCA.

Year	Overseas	Japan
	ISO/TR 14047 (2003) was issued as a collection of LCIA cases.	Japanese LCIA method began to be used for domestic companies' environmental impact assessment.
2004	Discussions were held about European research institutes' joint project for relating characterization to damage assessment (Recipe Project).	2nd-term LCA Project began.
		JEPIX (Japanese Eco-scarcity method) was published (Miyazaki 2003) and was used for assessment of companies' environmental performance.
		The 6th International Conference on EcoBalance was held.
2005	A revised version of ExternE Project was issued, including the range of integration factors for CO_2 and others.	Institute of LCA was established. The 1st annual meeting was held. LIME1 Guide was issued (Itsubo et al. 2005).
2006	ISO rearranged ISO 14040 to 14043 and issued ISO 14040 and ISO 14044.	2nd-term LCA Project ended. The list of factors for LIME2 was disclosed.
	2nd-term UNEP/SETAC LC Initiative began. The concept of the LC approach was proposed.	The 7th International Conference on EcoBalance was held. Main contents of research for LIME2 were published.

[First half of the 1990s: Issuance of the LCA Guide and proposal of a characterization method]

The history of LCIA began in the second half of the 1980s when the Society of Environmental Toxicology and Chemistry (SETAC) adopted LCA as a research theme and began to discuss LCA research regularly at annual meetings. In the 1990s, pioneer organizations issued documents regarded as LCIA guides one after another to construct the framework of LCIA. A list of characterization factors for each impact category was disclosed by Leiden University's Institute of Environmental Sciences (CML) in Holland in 1992 (Heijungs et al. 1992) and by North European countries in 1993 (Lindfors 1995). These guidelines not only cited from other documents the Global Warming Potential (GWP) (IPCC 2001), the Ozone Depletion Potential (ODP) (WMO 1999), the Photochemical Ozone Creation Potential (POCP) (Derwent et al. 1996), and others but also contained originally developed factors, such as acidification, human toxicity, and biological toxicity. At the same time, SETAC issued the Code of Practice (Consoli et al. 1993) and concretely showed the names of impact categories of LCIA. Through this publication, the concept of LCIA was created – that is, correlating the amounts of potential impact on impact categories, such as global warming and ozone layer destruction based on inventory. Later, such a method was called "characterization," and ISO considered this a mandatory element of LCIA (ISO 14044 2006).

With regard to weighting methods for environmental impact, the eco-scarcity method (Ahbe et al. 1990, Braunschweig et al. 1993) and environment priority strategies (EPS) (Steen et al. 1992) were developed or proposed in Switzerland and Sweden respectively. However, because both methods directly related environmentally damaging substances with single index without via characterization, their relation with the above-mentioned characterization methods was weak.

In response to the publication of guides and various research cases concerning LCIA, ISO established TC (Technical Committee) 207 in 1993 and began discussions for the creation of international standards for LCIA, a component of LCA. After that, LCIA was widely recognized as one of the main steps of LCA, and research activities for the development of methods became more active.

[Second half of the 1990s 1: Attention to and criticism of weighting methods]

In the second half of the 1990s, methods to fuse characterization and weighting were proposed. While countries were developing such methods, the limits of weighting were pointed out, and the signification of integration was discussed. With regard to characterization methods, methodological problems were pointed out, such as consideration for regional characteristics and introduction of fate analysis, and researches for solving such problems became active.

Eco-indicator 95, which was published in 1995 by Goedkoop (1995), aims to carry out integration by dividing the result of characterization by the amount of annual impact to make it non-dimensional, and multiplying the result by the weighting factor for each impact category. This method drew attention as a method to fuse characterization and integration, which traditionally had been examined separately. The distance-to-target (DtT) method (see Column 3.1-1) was adopted to calculate the weighting factor from the ratio of the current amount of impact to the expected amount of impact after reduction. After that, because the DtT method can relatively easily set weighting factors, many integration methods that adopted the DtT method were proposed (for example, Hauschild et al. 1998, Lee 1999, Itsubo 2000, Matsuno et al. 1999). In addition to the DtT method, methods for weighting impact categories based on questionnaires to consumers or expert discussions were proposed (such as Nagata et al. 1995, Yasui 1998).

With progress in the development of methods, it was recognized that individuals' subjective judgment of value would be inevitably introduced into weighting. Although the single index gained through integration facilitates the interpretation of the result, problems remain in the reliability and representativeness of assessment results. Because of this, when ISO prepared international standards for LCIA, a lot of discussions were held about whether to recognize integration as a step of LCIA.

According to ISO 14044 (former ISO 14042), which provides the procedure for carrying out LCIA, one of the most important matters is that a certain view was presented about what characterization and integration should be. That is, the characterization method that can be developed only by the use of knowledge of natural science was regarded as a mandatory element, while the step of weighting that contains the developer's and the practitioner's judgment of value was regarded as an optional element, although it was recognized as an element of LCIA. In this way, integration was clearly discriminated from characterization. The international standards of LCIA that contain the above-mentioned matters greatly contributed to the prompt dissemination of LCIA. ISO 14040 and 14044 specify the general procedure, framework, and requirements of LCIA, but do not specify any specific methodology or way of use. Concrete ways of using LCIA methods and showing results are explained in a report (TR 14047[*4]).

[*4] TR: Technical Report

[Second half of the 1990s 2: Improvement of characterization factors and proposal of damage assessment]

In the second half of the 1990s, discussions were held to solve problems in the characterization factors proposed so far. With regard to the traditional characterization factors that deal with chemical substances, consideration was hardly given to the relation with the processes from the emission of a substance to the exposure of it (which is called "fate and exposure analysis"). As for fate analysis, because a lot of discussions had already been held concerning risk assessment and atmospheric environment, characterization factors were developed with consideration for the properties of chemical substances through examination for reflecting the results of the discussions in LCIA methods (Guinée et al. 1996, Matsuzaki et al. 1997, Hertwich et al. 1999, Hauschild et al. 1998). Moreover, because, even if inventory is the same, actual environmental impact differs among emission regions, it was pointed out that the spatial differences of environmental impacts should be taken into consideration for LCIA. As a result, a lot of researches began to deal with this problem (Potting 1997, Krewitt et al. 1999, Huijbregts 2000). A revised version of the impact assessment method developed by Hauschild through Denmark's national project (EDIP) included a list of characterization factors for each country concerning local impact categories, such as acidification and eutrophication.

Meanwhile, discussions for the development of integration methods reached a turning point when many arguments arose against the method for integration through weighting among impact categories based on the result of traditional characterization (this method was called "midpoint modeling"). Müller-Wenk et al. (1997) pointed out that, to improve the transparency of weighting, it is necessary to conduct the assessment of damage to endpoints before weighting. Hofstetter (1998) adopted as a damage index the Disability Adjusted Life Year (DALY) used by the World Health Organization (WHO) as an index for health impact and developed frameworks whereby the impact of carcinogenic substances and air polluting substances can be assessed by the use of knowledge of natural science. Many of these frameworks were adopted in a revised version of Eco-indicator (Goedkoop et al. 1999). After these proposals were made, the methodology of using the result of damage assessment for weighting (which is called "endpoint modeling") rapidly drew attention. Moreover, research and development of a damage assessment method that serves as a base for an endpoint-type LCIA method has drawn the greatest attention as a new LCIA research field.

[Second half of the 1990s 3: Beginning of development of a Japanese LCIA method]

In the first half of the 1990s, most of the LCA researches and investigations in Japan dealt with LCI, whereas few researches were conducted for the development of LCIA methods. It was not until the second half of the 1990s that attention was drawn to the development of characterization factors based on the environmental conditions in Japan (Moriguchi 2000) and the development of weighting methods (Itsubo 2000, Matsuno et al. 1999, Nagata et al. 1995, Yasui 1998). However, it could not be said that they fully followed the rapidly growing level of LCIA research in Europe.

In 1995, to improve the domestic level of LCA promptly through active exchange of information among the parties concerned, the LCA Society of Japan(JLCA) was established (secretariat: Japan Environmental Management Association for Industry(JEMAI)). The members of the Forum, which mainly consist of industrial, academic and government persons concerned with LCA, prepared an LCA forum report and an LCA policy statement to make suggestions about the measures to be taken by Japan in the future. In response to the suggestions, the LCA National Project was started by the Ministry of Economy, Trade and Industry(METI), the New Energy and Industrial Technology Development Organization (NEDO), and JEMAI. The LCA National Project conducted the development of LIME in addition to the development of an inventory database authorized by industrial associations and the construction of a data system whereby data can be obtained through the Internet. Main research results at the time of the development were published mainly at International Conferences on EcoBalance and workshops (sponsor: National Institute of Advanced Industrial Science and Technology), activating exchanges with users and academic experts.

[2000s 1: Full-scale development of damage assessment methods]

After Müller-Wenk and Hofstetter pointed out the importance of damage assessment, the development of damage assessment methods became active. Müller-Wenk developed damage factors to assess the health impact of road traffic noise. Hofstetter and Krewit developed them to assess the health impact of air polluting substances. Cretattz developed them to assess the health impact of toxic chemicals. They all adopted damage indexes based on the loss of life expectancy. Moreover, damage factors were developed by Lindeijer concerning the impact of land use on plant growth, by Meent concerning the impact of chemical substances on the extinction of species, and by Goedkoop et al. concerning the impact of acidification and eutrophication on the disappearance of plant species (Lindeijer 2000, Meent 1999). In Japan also, the results of researches on the development of damage assessment methods were frequently presented at International Conferences on EcoBalance and other meetings. With the development of damage assessment, damage assessment was required to be clearly distinguished from characterization. The revised version of the LCA Guide that CML published in 2001 contained lists of factors recommended for both characterization and damage assessment concerning each impact category.[*5] At a workshop held by the US Environmental Protection Agency (US EPA) for discussions about the usefulness of characterization and damage assessment, it was recommended that the two methods be used according to their purposes, supplementing each other, because they have different advantages and disadvantages. The damage assessment method for LIME2 is explained in Chapter II “Characterization and Damage Assessment Methods,” while details of damage indexes are explained in Section 1.4.3 “Definition of Damage Index.”

[2000s 2: Development of methods based on endpoint modeling and economic assessment methods]

While damage assessment methods were actively developed, integration methods shifted from the approach to weighting across the results of characterization to the approach to weight across damage assessment results. All the main LCIA methods developed recently, including LIME, EPS, ExternE, Eco-indicator 99, and Impact 2002, are based on endpoint modeling.

[*5] According to the CML Guide, characterization is called “midpoint approach,” while damage assessment is called “endpoint approach.” Many European countries follow this.

The indexes for integration results are classified into non-dimensional indexes or economic indexes. Economic indexes have been adopted for an increasing number of research cases. This is because of the following:

1) Because economic indexes are suitable for daily living activities, communication can be facilitated.
2) Environmental economic researches have reached a sufficient level to be applied to integration methods for LCIA.

Of the above-mentioned integration methods based on endpoint modeling, LIME, ExternE, and EPS use economic assessment methods.

Explanation of the methods based on endpoint modeling and detail of environmental economic assessment can be found in 1.2 "Theme oriented method and damage oriented method" and 3.2 "Environmental economic assessment and conjoint analysis," respectively.

[2000s 3: Diversification of assessment]

Although LCA has so far been firmly established as a method whereby 1) companies assess 2) products 3) from the viewpoint of the environment, the entity that conducts assessment, the object of assessment, and the viewpoint for assessment have been diversified with the development of LCA researches and an increase in social concern.

In the second-term LCA National Project of Japan, an LCA method was developed to support local governments' decision making on environmental policies. This method included the development of tools for calculating environmental impact directly or indirectly accompanying attraction of companies and for selecting waste disposal bases, optimizing them from environmental and economic aspects.

In addition, because of an increasing concern in CSR, the momentum toward comprehensive assessment of corporate activities as a whole increased, and more than 700 companies disclosed environment reports and CSR reports. Many of the reports quantitatively showed the results of environmental activities by the use of environmental accounting and environmental efficiency indexes, and inventory databases for LCA and LCIA methods were used for the assessment of the results.

Moreover, because, with the promotion of environmental efficiency and the use of factors, interest increased in the development of indexes that integrate economic and environmental aspects, domestic companies proposed original indexes and used them for internal decision making and external information disclosure. In addition, to fulfill CSR, they were required to develop methods for quantitatively assessing TBL (Triple Bottom Line) – that is, environment, economy, and society – from the viewpoint of life cycle.

[2000s 4: Development of interdisciplinary interaction]

Although LCA researches have so far been carried out mainly in developed countries, such as European countries, the US, and Japan, activities for infiltrating the idea of life cycle into developing countries have become active. In UNEP/SETAC Life Cycle

Initiative, to promote LCA promptly in developing countries, a working group of LCA researchers was established to collect and arrange the results of leading researches. The Japan External Trade Organization (JETRO), the Asian Productivity Organization (APO), and the Asia-Pacific Economic Cooperation (APEC) held LCA seminars several times for government officers and environmental experts in Asian countries to support the introduction of LCA positively. In response to this, China, South Korea, Thailand, and Malaysia began national projects for creating inventory data for LCA. India, African countries, and South American countries also held international conferences on LCA, resulting in full-scale international exchange of information on LCA researches.

In Japan also, LCA researches have been recognized as a part of environmental science, and the Institute of LCA was inaugurated in 2006. The Institute of LCA is expected to lead society as a scientific institute that provides guidelines for realizing a sustainable society.

Column 0.1-1

Process of life cycle assessment according to ISO 14044

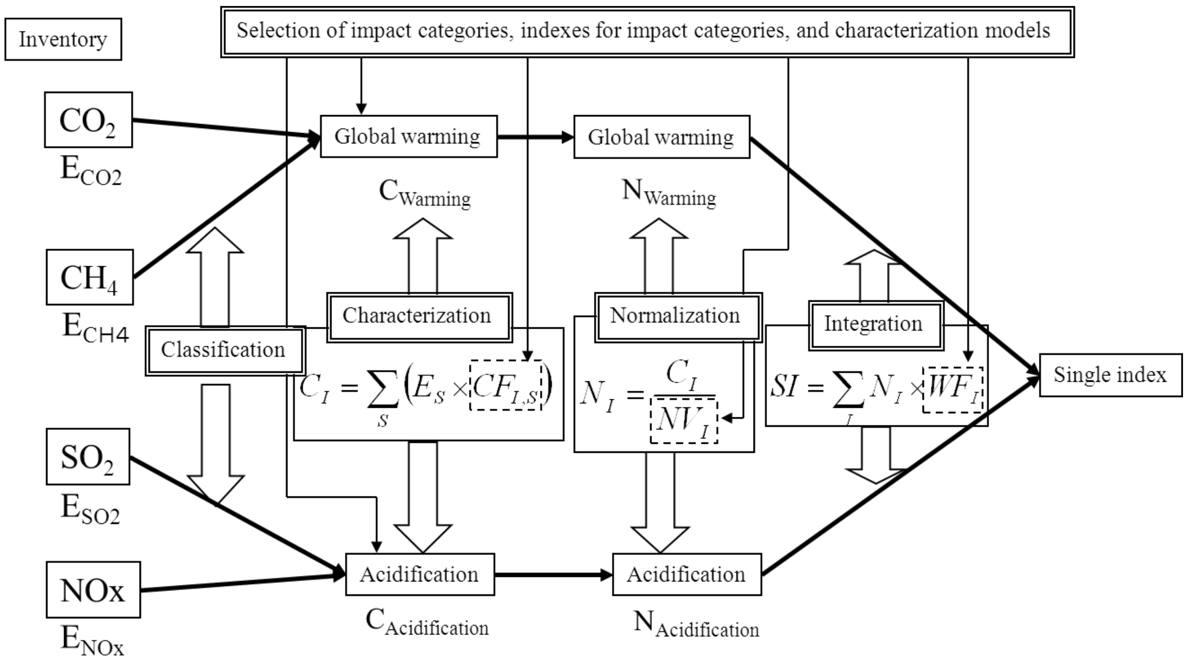


Figure 0.1-1: General procedure for life cycle impact assessment (prepared by the author based on ISO 14042)

S: substance; E: inventory; I: impact category; C_1: characterization result; N_I: normalization result; S_I: integration result; $CF_{I,S}$: characterization factor in impact category I; NV_I: standard value in impact category i;WF_I: weighting factor

(1) Selection of an impact category, a category indicator, and a characterization model

Identify an impact category (such as global warming), a category indicator index associated with it (such as infrared radiation [W/m^2]), and a model used for assessment (such as the IPCC model) beforehand. If these are shown in a report, the transparency of assessment results will be secured.

(2) Classification

Allocate the results of LCI among the relevant impact categories. This results in the allocation of two or more environmentally damaging substances in each impact category. If an environmentally damaging substance contributes to two or more impact categories, allocate it to all the relevant impact categories (for example, NOx is allocated to both photochemical oxidant and acidification).

(3) Characterization

Potential impact on an impact category differs depending on the substance. Taking into consideration this difference, calculate the potential environmental impact of the product system on each impact category. Calculation consists of conversion of the units for the LCI results into a common unit and cumulative addition of the results. A characterization factor is used for this conversion (for example, GWP in the case of global warming). This enables aggregation of LCI results for each impact category instead of each substance as before and clarifies which substance gives the largest contribution in the target impact category.

(4) Normalization

Normalization is carried out to understand the relative strength of the product system subject to assessment. Calculation is carried out by dividing the result of characterization by the referential datum (for example, the annual impact in Japan). The result is indicated non-dimensionally (for example, the degree of contribution to the environmental impact of the product subject to assessment on the total impact in Japan). This clarifies what impact category receives a large contribution from the object of assessment.

(5) Grouping

Grouping is allocation of impact categories to one or more groups. Depending on purpose, the allocated impact categories are rearranged or ranked. Because there are various impact categories, grouping is carried out as a measure to facilitate the interpretation of assessment results.

(6) Weighting

The weighting factor established based on the sense of value is used for converting various impact category results and, if possible, putting them together into a single index. In many cases, a single index is derived by multiplying the result of normalization by a non-dimensional weighting factor.

(7) Qualitative analysis of data

This is carried out to extract processes and data that have important influence on LCIA results or to obtain information on the uncertainty or sensitivity of LCIA results. Concretely, Pareto analysis, uncertainty analysis, and sensitivity analysis are used. The result of the analysis is used for obtaining guidelines for carrying out LCA repeatedly.

Of them, (1) to (3) are defined as essential elements because they are within the extent of assessment by the use of knowledge of natural science, while (4) to (7) are considered optional elements because they can be effective depending on the practitioner’s purpose, but subjective judgment of value is inevitably introduced.

Although many LCIA methods have been proposed because of the development of LCIA research, there was a period when excessive information made it difficult to understand the contents or put them into practice. ISO's standardization of LCIA procedures greatly contributed not only to the promotion of practitioners' understanding of LCIA but also to the prevention of establishment of too many of approaches LCIA methods.

0.2 Current situation of environmental assessment methods and trends in the use of LIME

Although LIME was developed as an environmental assessment method for LCA, it can be used for other environmental assessment tools on condition that data corresponding to inventory should be obtained. Table 0.2-1 shows environmental assessment tools for which LIME can be used. Various environmental assessment methods proposed so far can be divided by the object of evaluation, such as products, companies, and other entities; society, countries, and the world. In addition, they can be divided into those for assessing environmental impact and those for gaining economic indexes. Because LIME can be used not only as an environmental impact assessment method but also as an economic assessment method through integration, it is applied to various methods shown in Table 0.2-1. This section describes trends in the use of LIME for each environmental assessment method.

Table 0.2-1: List of assessment methods for which LIME can be used

Object of assessment	Product	Company	Society, country, world
Use as an environmental impact assessment	LCA, environmental efficiency, factor, cost-benefit analysis	Environmental performance assessment, environmental efficiency, factor	Sustainability index
Use as an economic assessment method (for measuring social cost)	Material flow cost accounting (MFCA), cost-benefit analysis, full-cost assessment	Environmental accounting	Green GDP

0.2.1 LCA

Environmental burdens occur through economic activities. For example, when oil or coal is burnt as energy, CO_2 and SO_2 are produced through acidification of the carbon and sulfur contained in the oil or coal. They cause environmental impact, such as global warming, acidification, and air pollution. Even for the purpose of solving environmental problems, people cannot fully escape from their current lives. Therefore, people are required to continue their lives at a sustainable level by reducing environmental burdens while maintaining current standards of living. This requires a comprehensive review of all products and services and finding a way to reduce the total amount of environmental impact effectively.

LCA is a tool for assessing environmental burdens and environmental impact quantitatively at all the life cycle stages of the target product, ranging from collection of raw materials to the acquisition of materials, and the manufacture, use, disposal, and recycling of the product. The use of LCA enables the acquisition of useful information on which product is environmentally predominant and what matters should be previously discussed to reduce the environmental burden of the target product effectively. The company can use the information for determining environmental management policy through distribution of it to the staff or to publicly announce that its product is environmental-friendly.

It is said that the use of LCA began in the 1970s. At that time, LCA was conducted on beverage containers and other simple products. In Japan, LCA began to draw attention in the 1990s and has rapidly become popular in recent years. Table 0.2-2 shows main LCA research cases presented at meetings of the Institute of Life Cycle Assessment. As shown in the table, LCA has been applied not only to energy, materials, and simple products but also to home electronics, office equipment, transportation machinery such as railroads and automobiles, structures such as houses and buildings, and large and very complicated industrial products. Recently, many assessment cases have been specialized in the venous sector, such as recycling and waste disposal, and have also covered industries other than manufacturing, such as e-learning and information and communications technology (ICT) as well as agriculture and fishery.

LCA began to draw a lot of attention when it was recognized as a useful support tool for the construction of companies' environment management systems (EMS) and ISO began to standardize the general procedure for LCA. The standards for LCA, ISO14040 to 14043 [*6] have already been published as international standards. Although the standards have not specified the details of methodology, they show the structure of LCA and the minimum requirements for LCA, greatly contributing to the international promotion of LCA.

Because the original purpose of LCA is to obtain information for reducing environmental impact effectively, it was expected to be used for companies' decision-making on optimization of supply chain and process and selection of parts and materials. Recently, however, LCA has been frequently used as a tool for companies' showing the environmental superiority of their products. A typical case is Environmental Label Type III. The Japan Environmental Management Association for Industry registered and published LCA results about more than 450 products through the system of Ecoleaf, its environmental label.

Table 0.2-2: Main LCA research cases presented at meetings of the Institute of LCA: 2005 (first meeting), 2007 (second meeting)

Category	First meeting	Second meeting
Energy	Coal-based clean energy, micro hydraulic power generation, portable fuel power generation by use of biomass, storage battery, micro fuel battery	Biomass energy, DME manufacturing, woody biomass power generation, woody biomass fuel for transport, power generation technology, home cogeneration system
Material/simple product	Stationery, woody resources, eco material, stainless steel, precious metals, iron/steel industry, bio-plastic, bio-toilet	Alumidoross MFA, copper/cooper alloy, concrete material, textile products, eco-electric wire, PLA white tray, clothing, consumer durables
Electric/electronic machinery	Mobile phone, solder, IC package, refrigerator, automatic vending machine, air conditioner, home lighting, electronic equipment, network infrastructure	Printed board, ICT system, TV conference, washing machine, dry cleaning, replacement of energy-saving home electronics, lighting equipment, ICT solution, e-learning, TV, PC, assessment of mobile phone including recycling, piezoelectric element (fine

[*6] ISO14041, 14042, and 14043, which specified the requirements for the tasks from the setting of the purpose and the scope of research to the interpretation of the result, were reviewed and reissued as ISO14044 in 2006.

Category	First meeting	Second meeting
		ceramics), lithium ion battery, pellet stove, cost-benefit analysis of electronic equipment
Houses/buildings	Wood house, construction material, adhesive, housing energy consumption, concrete material	Concrete material, local structural wood, processing/assembly of structure, structural material, woody construction material, school, biomass conversion plant, particle board, LCA for heat island measures, factory assessment
Transport/large products	Ship, aircraft, medium-weight passenger transport means, LRT system, large pump	Large pump, energy-saving railway, traffic system, passenger transport system, VOC absorbing wall material, passenger car, land use traffic model, TV conference
Recycling	Automobile, PET bottle, general waste disposal, final disposal site, methane ferment digestive disposal, urban venous system, forest waste use, garbage, zero emission project, construction waste, beer case, FRP disposal, battery	Livestock excreta disposal system, food waste, PET bottle, sewage treatment system, waste flow analysis of Aichi International Exposition, waste incineration system, construction waste, used mixed plastics for home electronics, home electronics, plastic, solid waste disposal, waste edible oil, sewage system, clothing, waste construction wood, water disposal equipment, intermediate waste disposal technology, garbage biogasification
Beverage/food, agriculture, fisheries	Beverage supply system, distribution/sales of soft drinks, recipe of pasta, environmental household account book, consumption behavior analysis, agriculture on Miyako Island, squid fishing	Dairy farming, rice, wheat flour, bread, bean oil, white sugar, strawberry jam, tomato, marine products, pork production, environmental burden of dining out, environmental burden of cooking, farm production system, draft beer barrel and sales system, domestic thinning, water use system

Column 0.2-1

Procedure for carrying out LCA

ISO14040 and 14044 specify the procedure for carrying out LCA and the requirements for using LCA. According to them, LCA consists of the following four steps:

(1) Setting the purpose and the scope of research

Clarify the purpose of LCA and determine the scope of research. The scope of research includes not only the scope of the assessment process but also , impact categories, and the assessment models.

(2) Life cycle inventory analysis (hereinafter referred to as "inventory" or "LCI")

Calculate the environmental burdens of all the related processes and find the amount of environmental burden of the whole life cycle by summing up the burdens while considering the connections among them. The result is expressed in terms of physical amount, such as quantity, concerning each environmentally damaging substance.

(3) Life cycle impact assessment (hereinafter referred to as "impact assessment" or

"LCIA")

Assess the amount of potential environmental impact that can be caused by the environmental burden. Assessment may be made of potential contribution to an environmental problem, such as global warming, or the amount may be expressed by a single index through weighting of various environmental impacts. The manner of expressing the result varies among the steps of LCIA or depending on the evaluation method.

(4) Life cycle interpretation (hereinafter referred to as "interpretation")

Based on the results of the analysis and assessment so far, consider what process, substance, or impact category is important. Moreover, examine the reliability of the data used for LCA, centering on especially important processes and assumptions. If necessary, reexamine it to improve the accuracy. Draw a conclusion from these results. For detailed explanation of LCA, see Editorial Committee on an Introduction to LCA Practice (1998), Adachi et al. (2004), Ishikawa et al. (2001), and Itsubo et al. (2007).

ISO divides the LCA procedure into several steps (see Column 0.2-1). Among them, inventory analysis takes the most time and effort for the LCA practitioner. If inventory data on electric power and basic materials used for many products are open to the public, the time for the analysis will be halved by effective use of the data.

The same applies to impact assessment. If the impact assessment methods approved by domestic experts are open to the public, companies can obtain LCIA results consistent with the purpose by merely applying the inventory data on their products without developing an impact assessment method.

During the first-term National LCA Project, which began in 1998, the Ministry of Economy, Trade and Industry and NEDO considered constructing an LCA database, including the following:

- Highly representative inventory data supplied by industrial associations
- Highly reliable LCIA method developed under the participation of environmental scientists and academic experts
- Network system that can effectively deliver the results of the above-mentioned research and development and continue to update data

The results of the consideration were reflected in the national LCA database managed by LCA society of Japan Forum. Practitioners became able to collect data through the Internet easily, which promoted companies' use of LCA. Moreover, in the second-term National LCA Project launched in 2003, the use of the database for LCA was examined through case studies, with the result that venous inventory data and the impact assessment method were updated and regional LCA was newly carried out. Since 2006, a program for disseminating the results of research and development so far among small and midsize companies has been carried out.

LIME1 and LIME2 were developed through the above-mentioned project. Many companies have already begun to use LIME for the LCA of their products. As shown in Table 0.2-3, LIME has been used in various fields, such as electric and electronic equipment, transport equipment, construction and construction materials, recycling, and services. The following are main cases:

Table 0.2-3: Main LCA cases by the use of LIME

Industry name	Object of assessment	Practitioners
Home electronics	TV, display	Iiyama, Toshiba, Musashi Institute of Technology
	Refrigerator	Toshiba, National Institute of Advanced Industrial Science and Technology (AIST)
	Washing machine	Hitachi
	Air conditioner	Toshiba Carrier
	Cleaner	Toshiba
	Stove	Nagano Prefecture
	Hot-water system	Noritz, Toshiba Carrier
	Mobile phone	AIST, Toshiba, Musashi Institute of Technology
	HDD player	Toshiba
	Audio player	Toshiba
	Dish washing/drying device	Toshiba
	Rice cooker	Toshiba
	Warm-water toilet seat	Toshiba
	Lighting equipment, lamp	Toshiba
Office equipment, parts	Inkjet printer	Canon, Seiko Epson
	Memory stick	Sony EMCS
	IC package	Shinko Electric Industries, Ibiden
	Fuel battery	Fujitsu Laboratories
	Color fadable toner	Toshiba
	Note PC	Fujitsu, Toshiba
	Scanner	Toshiba
	Copier	Matsushita Electric, Ricoh
	Liquid-crystal projector	Seiko Epson, Hitachi
	Liquid-crystal panel	Samsung
	Digital camera	Toshiba
Transport equipment	Automobile	Japan Automobile Research Institute, Toyota Motor, Nissan Motor, AIST
	Automobile parts	Japan Auto Parts Industries Association
	Railway	Railway Technical Research Institute, Nagoya University
	Ship	National Maritime Research Institute
Public works, construction, construction materials	Bridge	Taisei Corporation, Hanshin Expressway
	VOC absorbing wall material	INAX, Musashi Institute of Technology
	Recycled construction material	Sekisui Chemical
	Cement, concrete	J-Power
	Commercial facilities	Tokyu Construction
	Sash	Tostem
	Interior decorating sheet	Toppan Printing
	Urethane	Bridgestone
	Elevator	Toshiba
	Solar snow melting system	Solar System
Energy	Electric power	Tokyo Electric Power, Kansai Electric Power, Chubu Electric Power
	Gasoline, light oil	Nippon Oil Corporation
	Biodiesel	AIST
Material, simple products	Adhesive	Aica Kogyo, University of Tokyo
	Paint	Kyowa Hakko
	PET bottle	Dai Nippon Printing

	Steel can	Toyo Seikan
	Paper cup	Printers Association of Japan
	Containers and packaging	Nisshin Seifun
	Garbage bag	Nippon Film
	Lead-free solder	Hitachi
	Wood, thinning	Tokyo University of Agriculture and Technology, Musashi Institute of Technology
Daily necessities	Detergent	Kao
	Disposable diaper, sanitary items	Unicharm
Recycling, waste disposal	Waste wood recycling	National Institute for Environmental Studies
	Waste plastic	AIST
	Livestock excreta disposal system	AIST
	Food waste recycling, garbage recycling technology	AIST, Musashi Institute of Technology
	Zero emission project	University of Tokyo
	Demolition waste	AIST
	Home electronics recycling	Musashi Institute of Technology
	Sewage disposal	Musashi Institute of Technology
Service	PC lease	NEC Lease
	ICT solution	Fujitsu Laboratories
	Washing, dry cleaning	University of Tokyo
Other	Guitar	Yamaha
	Agriculture	National Institute for Rural Engineering
	Unfreezable faucet	Takemura Seisakusho

The Japan Automobile Research Institute (Funazaki 2006) integrated environmental impacts on gasoline automobiles and diesel automobiles. The result is shown in Figure 0.2-1. Changes in environmental impact were assessed from the 1990s to the second half of 2000. In the 1990s, because the health impact of the emission of suspended particulate matters (SPM) was serious, diesel automobiles generally had greater environmental impact. However, because of the strengthening of regulations and accompanying improvement of environmental technologies, the emission of air polluting substances was reduced. Moreover, by following the post new long-term regulation applied from 2009, the environmental impact of diesel automobiles became almost the same as that of gasoline automobiles.

Dai Nippon Printing Co., Ltd. (Fujimori 2004a) conducted LCA of PET bottles by the use of LIME (Figure 0.2-2). Although the demand for PET bottles has increased, the demand for reduction in environmental burden and cost also increased due to an increase in raw material cost. The company confirmed that the environmental impact of PET bottles was reduced by about 30% by the following measures: 1) the weight of a PET bottle was reduced by reduction in thickness; 2) improvement of transport efficiency by transport of products before molding; and 3) reduction in power consumption by replacing heat sterilization with filling in a sterilized room.

The National Institute of Advanced Industrial Science and Technology (Sagisaka et al. 2006) used LIME for LCA of biofuels (Figure 0.2-3). Because carbon neutral, which offsets the emission of CO_2 caused from the use of fuels by the amount of carbon fixed

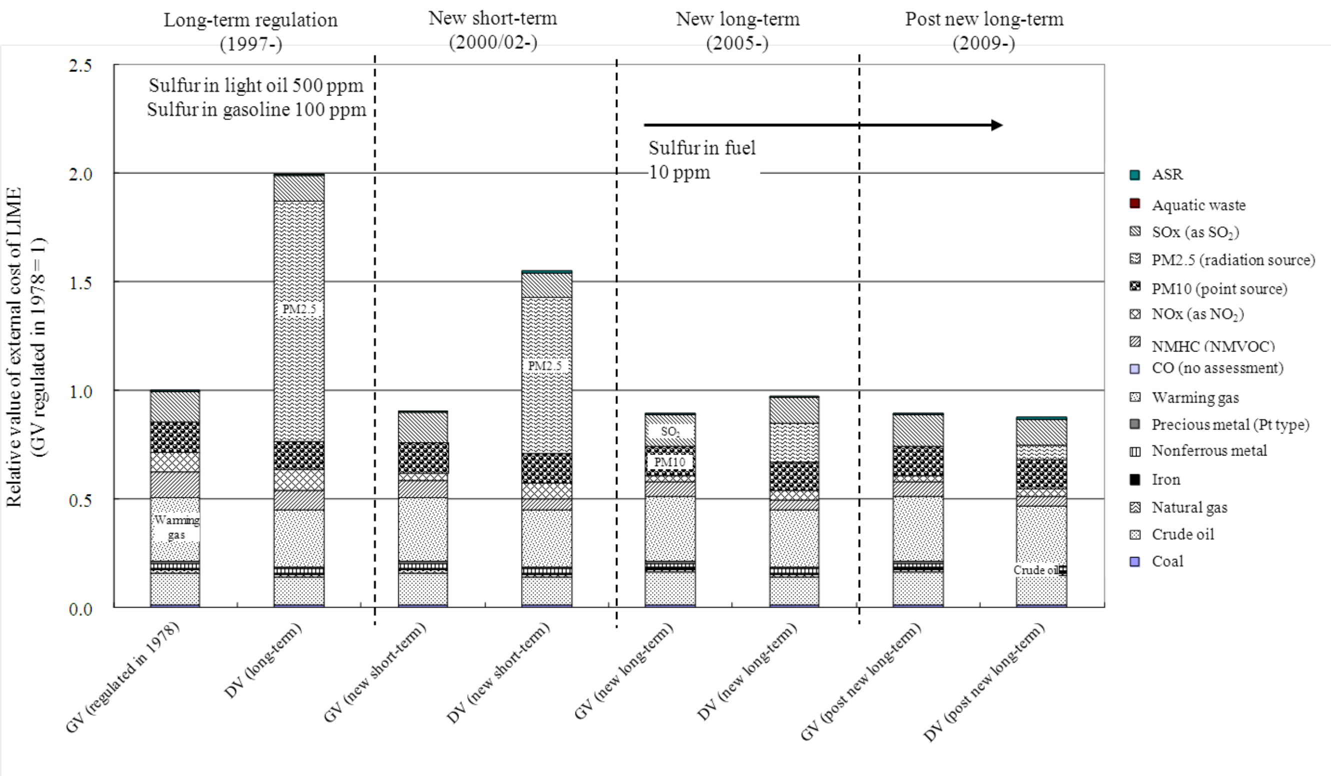


Figure 0.2-1: Environmental impact integration result of automobiles (gasoline vehicles and diesel vehicles) (Funazaki 2006)

Although at present diesel vehicles have greater environmental impact due to the emission of diesel exhaust, their environmental impact will decrease to almost the level of gasoline vehicles' because of technological development and measures for environmental regulation in the future.

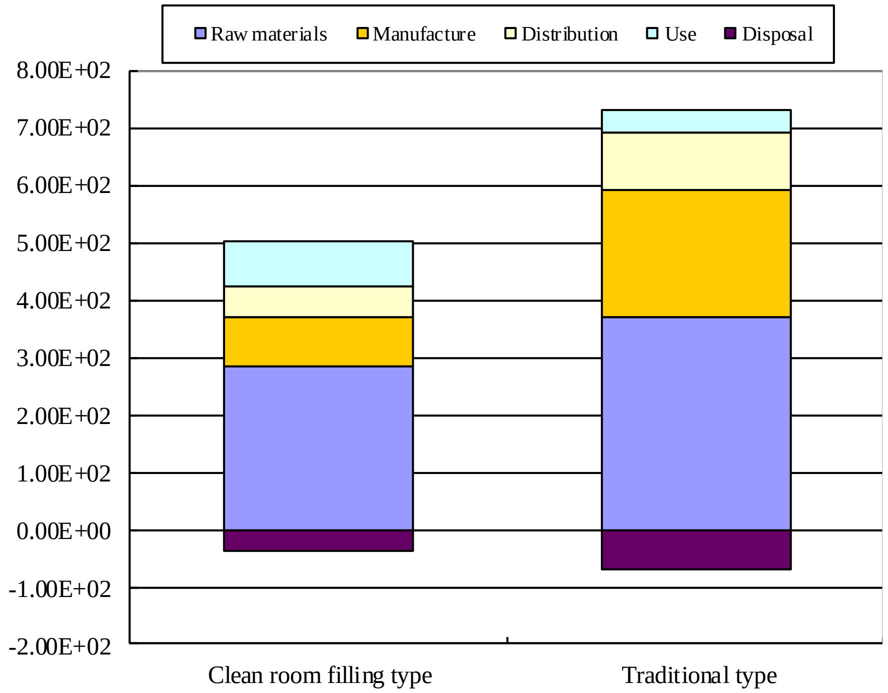


Figure 0.2-2: Environmental impact integration result of PET bottles (clean room filling type and traditional type) (Fujimori 2004)

It was confirmed that, although the clean room filling type has a great impact at the time of filling (use), the environmental impact as a whole can be reduced by reducing the weight of raw materials and improving the efficiency of distribution.

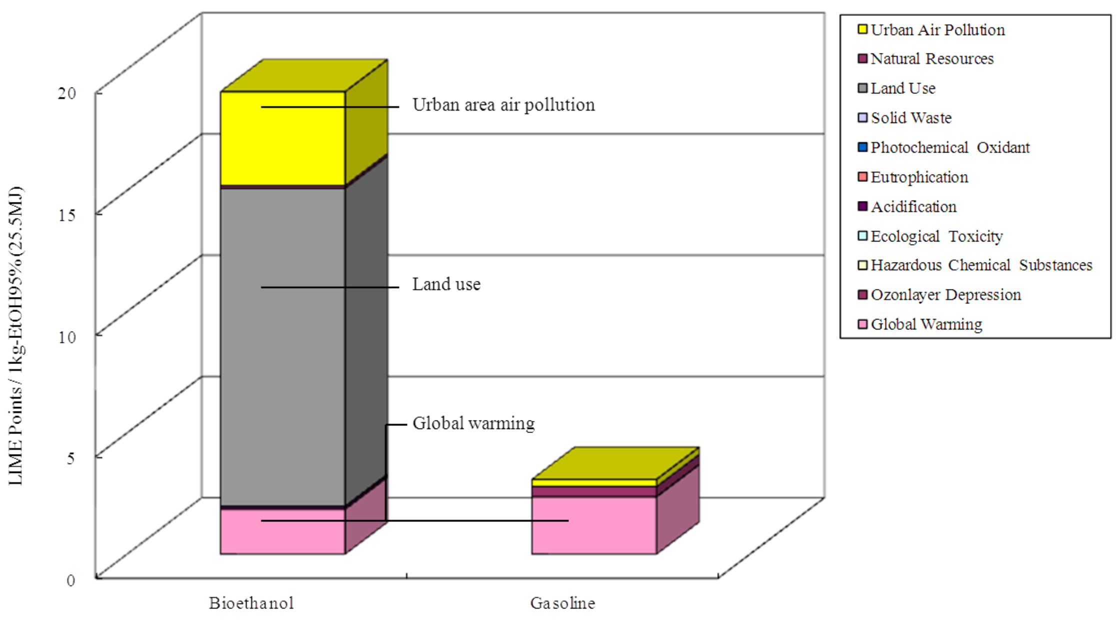


Figure 0.2-3: Result of LCIA of bioethanol (Sagisaka 2006)
Although Biofuels have a relatively low impact on warming through being carbon neutral, they have a great impact on human health due to the impact of land use on the ecosystem and urban area air pollution.

at the time of cultivation, can be applied to biofuels, biofuels are thought to be effective for global warming. However, in addition to urban area air pollution, such as NO_x, SO_2, and particulate matters (PM), biofuels have potential impact on land use for cultivation, indicating that environmental impact would increase as a whole.

Toshiba (Kobayashi 2004) has applied LIME to the assessment of the color fadable toner and used the results for the calculation of factors. This product requires erasing equipment for reuse of paper. However, even if the environmental burden of the use of the erasing equipment is taken into account, the reuse of paper has a greater effect of reducing environmental impact. Therefore, the introduction of the color fadable toner is highly significant (Figure 0.2-4).

INAX and the Musashi Institute of Technology (Kaneko et al. 2007) used LIME for the LCA of housing wall material that absorbs formaldehyde indoors. As shown in Figure 0.2-5, although this material has a great environmental impact when products are manufactured through incineration, it absorbs formaldehyde, a carcinogenic substance, at the stage of use, greatly contributing to the reduction of indoor air contamination. Therefore, it was assessed as contributing to the reduction of environmental impact on life cycle as a whole. In addition, although vinyl cloth, with which the wall material was compared, has a small environmental impact at the stage of production, it was thought that the formaldehyde emitted from the adhesive has a great impact at the stage of use. Therefore, it was estimated that the use of adhesive that reduces formaldehyde can reduce the environmental impact to a similar degree as the material that absorbs formaldehyde.

Although the density of formaldehyde emitted from construction materials can be reduced by increasing the number of times of ventilation, an increase in the number raises energy consumption, which may worsen global warming or air pollution. Chapter IV explains the result of analysis of construction materials with consideration for people's lifestyle.

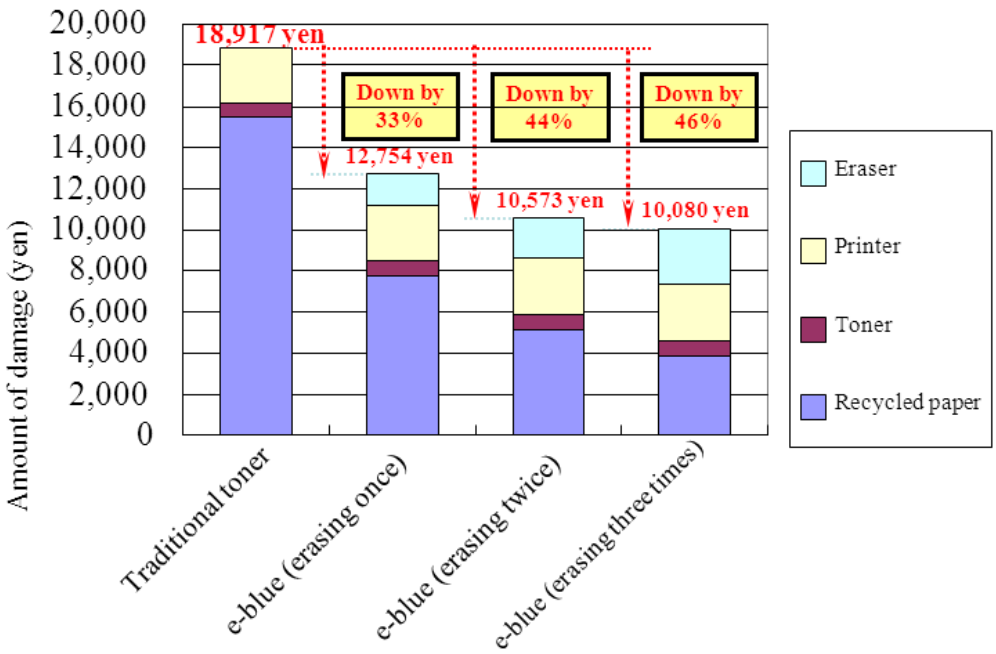


Figure 0.2-4: LCIA result of a color fadable toner

It was verified that the effect of promoting the reuse of paper (ecosystem conservation, etc.) is larger than an increase in the impact due to the introduction of an eraser.

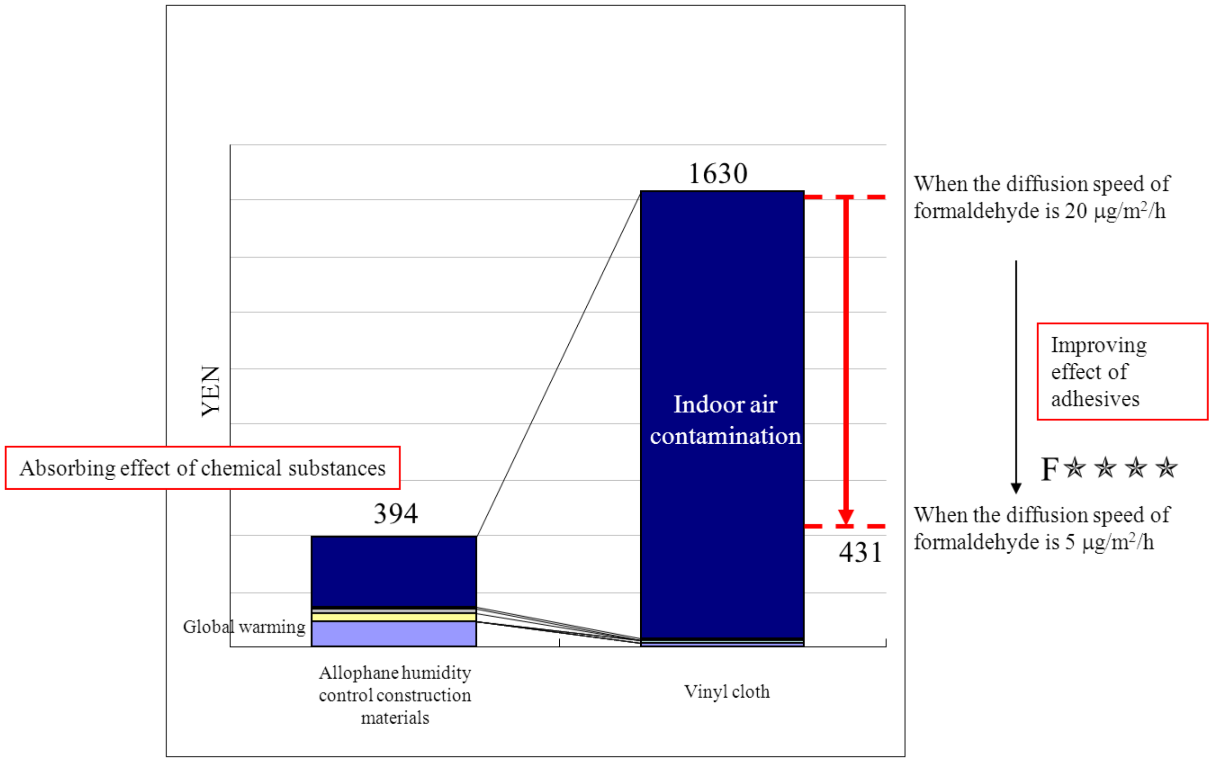


Figure 0.2-5: Result of environment impact assessment of formaldehyde-absorbing construction materials and vinyl cross (Kaneko 2007)

Environmental impact can be greatly reduced by the use of VOC-absorbing construction materials and adhesives that reduce the consumption of formaldehyde.

In Japan, LCA has often limited substances subject to analysis mainly to CO_2, NO_x, and SO_2. However, according to the results of the case studies explained herein, analysis limiting to the small number of environmentally damaging substances, such as CO_2, found that environmental impact was not fully grasped concerning some products. Because LIME enables the assessment of 15 impact categories and 1,000 substances, it is expected that the scope of LCA will be broadened and that the possibility can be found to grasp all the important environmental impacts that have so far been overlooked.

0.2.2 Environmental efficiency and factors

LCA is used for assessing the environmental aspect of products. However, it is impossible for profit-making companies to continue their businesses when only environmental aspect is taken into consideration. Therefore, it is important for them to balance economy with the environment. Environmental efficiency is an attempt to express the relation between the two by use of indexes. Environmental efficiency indexes were proposed at the "United Nations Conference on Environment and Development" held in Rio de Janeiro in 1992. The World Business Council for Sustainable Development (WBCSD) defines environmental efficiency as "construction of society that provides competitively priced goods and services that satisfy human needs and improve quality of life, while reducing impact on the ecosystem and resources to an environmentally acceptable level through minimization of resource consumption and environmental burden and maximization of services." As an index plainly indicating this definition, environmental efficiency is generally expressed as the ratio of the value of a product or service to its environmental impact (formula 0.2-1).

$$\text{Environmental efficiency} = \frac{\text{Value of product, etc.}}{\text{Environmental impact of product, etc.}} \tag{0.2-1}$$

In the case of an air conditioner, for example, a function, such as the cooling capacity (how much space), or an economic index, such as the price or the values added, is used as the numerator. Meanwhile, what is used as the denominator is the emission of CO_2, the result of characterization for an impact category, such as global warming, or the result of integration. However, because the numerator often differs in dimension from the denominator, a non-dimensional factor produced by comparison between the environmental efficiency of the new product and that of the former product is often used.

$$\text{Factor} = \frac{\text{Environmental efficiency of assessed product (new product)}}{\text{Environmental efficiency of base product (former product)}} = \frac{\dfrac{\text{Value of assessed product}}{\text{Environmental impact of assessed}}}{\dfrac{\text{Value of base product}}{\text{Environmental impact of base product}}} \tag{0.2-2}$$

There has been a growing trend toward the use of factors and environmental efficiency as in-house environmental management indexes. According to the Japan Environmental Management Association for Industry (2004), a total of 67 companies have introduced an environmental efficiency index and its factors at the corporate level and at the product level as environmental management indexes (Table 0.2-4).

Environment efficiency and factors, it is important to find the elements of each index. Although there are cases where environmental efficiency is calculated for each type of environmentally damaging substance, such as CO_2 and resource consumption, this increases the number of items of assessment results and reduces the clarity as a communication tool. As a result, an increasing number of companies use the environmental impact integrated by LIME as the denominator for environmental efficiency. Table 0.2-5 shows cases where business activities were assessed from environmental efficiency, etc. by the use of LIME.

Table 0.2-4: Companies that have introduced environmental efficiency indexes and factors (Japan Environmental Management Association for Industry 2004a)

(Unit: number of companies)

	Environmental report issuance confirmation companies	Environmental efficiency/factor-introducing companies	
		Product level	Company level
Manufacturing	317	12	41
Nonmanufacturing	106	1	13
Total	423	13	54

Table 0.2-5: Assessment cases by the use of LIME for environmental efficiency and factors

Company	Object of assessment	Index	Definitional formula	Period
Tokyo Electric Power	Business activities	Environment efficiency	Sales / environmental impact	1990-2006
Chubu Electric Power	Business activities	Environmental burden index	Environmental impact / electric energy sold	2000-2004
Kansai Electric Power	Business activities	Environment efficiency	Business profit / environmental impact	1990-2006
J-POWER	Business activities (group)	Environmental efficiency index	Electric energy sold / environmental impact	1990-2006
Nippon Oil	Business activities (16 main group companies)	Environment efficiency	Product production / environmental impact	2002-2006
Maruzen Petrochemical	Business activities	Environmental efficiency index, eco-efficiency index	Sales / environmental impact	2001-2005
Mitsubishi Gas Chemical	Business activities	Environmental efficiency	Sales / environmental impact	2002-2004
Toshiba	Toshiba business activities (group)	Factor T	Sales / environmental impact	2001-2006
Toshiba	Products (49 types)	Factor T	Value factor x environmental impact reduction factor	Comparison with base product
Fujitsu	Note PC	Factor X	Service (comparison between new and former products) / environmental impact (comparison between new and former products)	1996 and 2003
Nikkei BP	Publishing	Environmental performance	Environmental impact	2004
Unicharm	Business activities (group)	Environmental efficiency	Sales / environmental impact	2004- 2006

Company	Object of assessment	Index	Definitional formula	Period
Lion	Business activities (group)	Environmental efficiency	Sales / environmental impact	2000-2006
AIST	State, company	Environmental efficiency	Value added / environmental impact	Single year
AIST	Mie Prefecture Crystal Town Project	Environmental efficiency	Local effect / environmental impact	20 years
AIST	Digital camera	Environmental efficiency	Product value / environmental impact	Product life cycle

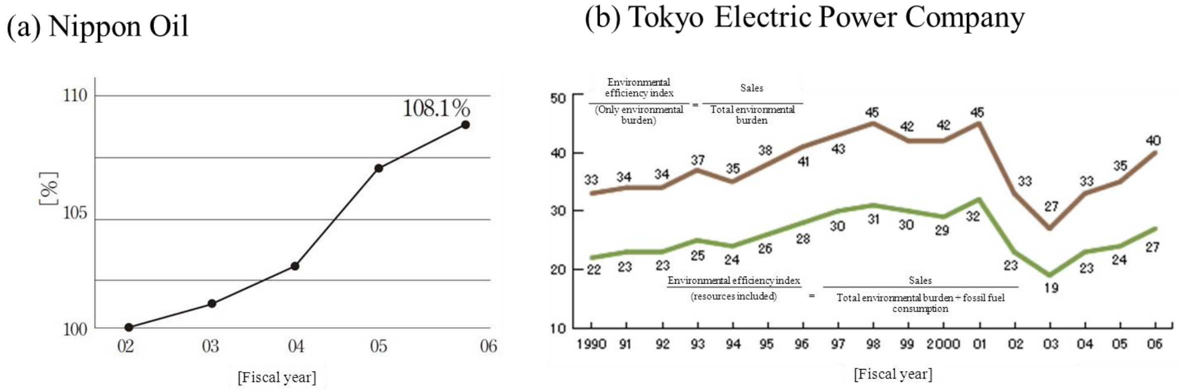


Figure 0.2-6: Examples of disclosure of environmental efficiency results
(a) Nippon Oil: continuous improvement in environmental efficiency;
(b) Tokyo Electric Power Company: disclosure of changes in environmental efficiency for 17 years from 1990

As shown herein, companies engaged in energy, such as electric power companies and oil companies, have been actively using LIME for the assessment of environmental efficiency. Nippon Oil (2007), Maruzen Petrochemical (2007), Tokyo Electric Power (2007), Kansai Electric Power (2007), and Chubu Electric Power (2004) calculated the environmental impact caused by their activities and product production or production output in the past five to fifteen years and examined secular changes in environmental impact by comparison between the two. As an example of the application of LIME to environmental efficiency, Figure 0.2-6 shows the results of assessment obtained by Nippon Oil and Tokyo Electric Power. The figure indicates that, because Nippon Oil increased environmental efficiency by more than 10% in the seven years from 1996, the year of start of research, to 2003, it continued to consider the balance between the environment and economy. Tokyo Electric Power disclosed the results of calculation of environmental efficiency over 17 years. Although environmental efficiency decreased for some time due to suspension of nuclear power generation, it is indicated that environmental efficiency has risen in the long term because of technological improvement.

Toshiba (2007) calculated factors by calculating environmental efficiency for various new products and comparing it with former products' environmental efficiency. Figure 0.2-7 summaries the result of calculation of factors for 49 items. The figure expresses the environmental impact reduction factor and the value factor with the vertical and horizontal lines, respectively. The characteristics of product groups were clarified by dividing the groups into a group of products whose environmental impact improved greatly, a group of products whose value increased greatly, and a group of groups whose

environmental impact and value improved synergistically. Details of the results have been published in an environment report and pamphlet prepared separately.
The National Institute of Advanced Industrial Science and Technology (AIST) proposed an environmental efficiency index that is an integration index whose numerator and denominator are value added and environmental impact respectively (Itsubo et al. 2004). The index enables the comparison and assessment of the state, companies, and products under the same concept (Figure 0.2-8). Adoption of value added enables its calculation by deducting the direct material cost from GDP in the case of the state, the profit and loss statement in the case of a company, and sales in the case of a product. For example, the state's environmental efficiency index can be regarded as the mean value of environmental efficiency for all products and business activities in Japan. If this index is prepared beforehand, it will be possible to assess whether or not the result of analysis of the environmental efficiency of business activities or a product is relatively good. The straight line passing through the origin in the figure indicates the average for the whole state. If a product exists above the line, its environmental efficiency is relatively high. Because the value-added rate differs among industries and groups of products, this figure cannot show which product is superior, but makes it possible to gain a guide for improvement of the environmental efficiency of a product. For example, in the case of a refrigerator, the environmental impact can be reduced by a change of the cooling medium from a specified CFC to an alternative CFC, and it is possible to confirm that the environmental impact has been improved as a result (it has become nearer to the domestic average in the figure).

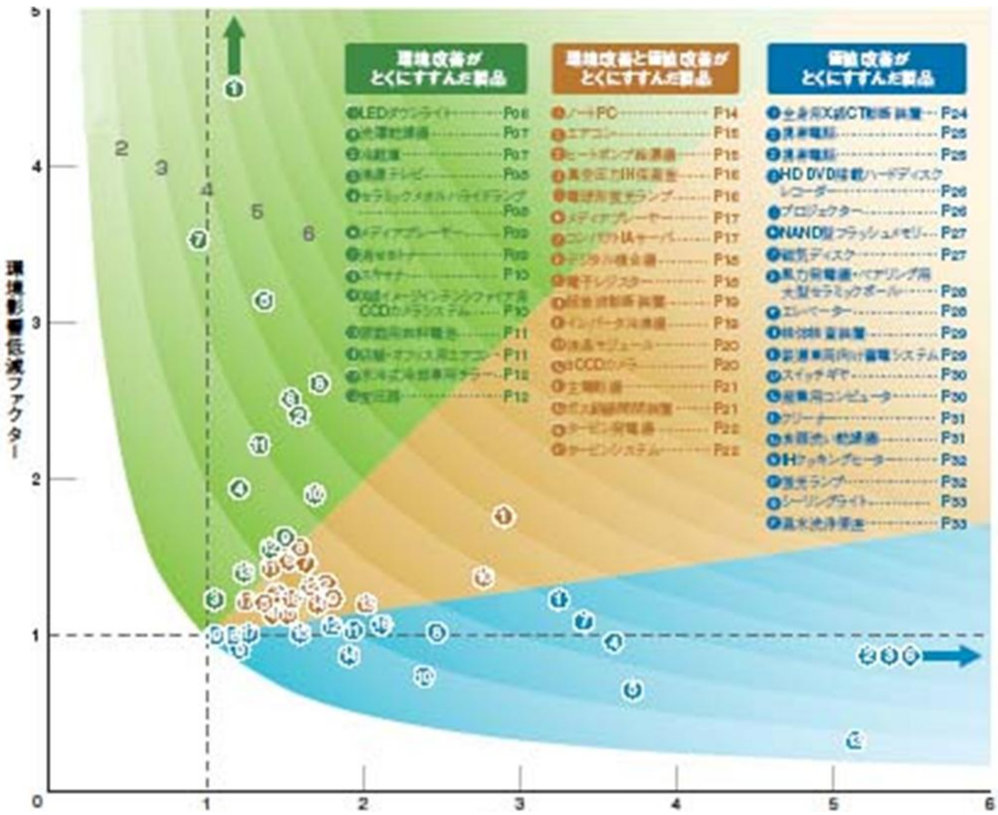


Figure 0.2-7: Result of calculation of factors for each factor of Toshiba
Both the product value and the environmental performance are assessed. The degree and form of improvement differ among products. Products are classified into those greatly improving in environmental performance, those improving in value, and those improving in both environmental performance and value.

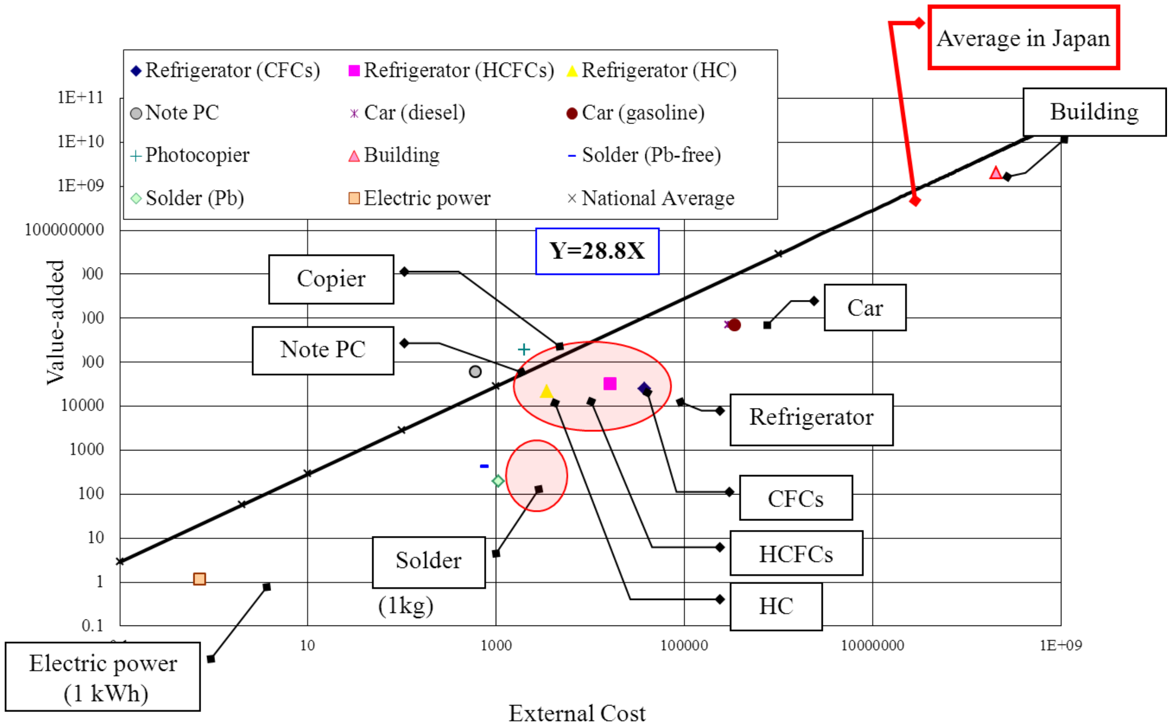


Figure 0.2-8: Environmental efficiency indexes for products and the national average
If indexes are located above the national average, the environmental efficiency is relatively high.
If value-added is adopted as the numerator of environmental efficiency,
comparison can be made among countries and among products.

0.2.3 Environmental accounting, cost-benefit analysis, full-cost assessment, material flow cost accounting

The result of integration by LIME is expressed by economic indexes. Because economic indexes can be used in various manners, they are often used for other environmental assessment tools. Concrete examples are environment accounting, cost-benefit analysis, full-cost assessment (FCA), and material flow cost accounting (MFCA). The use of economic indexes for these methods has already begun. Table 0.2-6 summarizes cases where the external cost of LIME is used for the above-mentioned methods. Below, the outlines of these assessment methods will be explained and then cases of use of LIME will be described.

(1) Environmental accounting

Environmental accounting is a tool for providing (recording, measuring, and delivering) accounting information on the environment (Inanaga 2000). Through environmental accounting, companies can gain information on how much they spend for environmental activities and what degree of effect they can gain from the environmental activities. Responding to a recent increase in people's awareness of environmental issues, companies have spent a lot of cost for environmental conservation. Therefore, to hold down the cost as much as possible and maximize the effect, it is extremely important for a company to calculate each department's expenditure and the total expenditure and grasp what degree of social effect is worth the cost or investment and what degree of economic effect the company will gain.

Table 0.2-6: Cases of use of LIME for economic analysis (environmental accounting, cost-benefit analysis, full-cost assessment, material flow cost accounting)

Analysis method	Implementing body	Object of assessment	Publication medium
Environmental accounting	Kyoto City	Water treatment system	Report
	Kansai International Airport	Airport	Environment report
	Kyowa Hakko	Business	Environment report
Cost-benefit analysis	Nippon Oil	ENEOS Vigo, low-sulfur light oil	Environment report
	NEC	Lease	Environment report
	Hitachi	Washing machine	Conference presentation
	Fujitsu Laboratories	Note PC	Conference presentation
Full-cost assessment	Shinko Electric Industries	IC package	Conference presentation
	National Maritime Research Institute	Ship	Software
	AIST	Waste plastics disposal	Conference presentation
	Seiko Epson	IJ printer	Website
	AIST	Local cooling/heating	Report
Material flow cost accounting	Tanabe Pharmaceutical	Medical supplies	Report
	Nippon Film	Garbage bag	Report
	Sanden	Aluminum casting, cutting work	Report
	Canon	Steel/stainless processing	Report

Environmental accounting consists of the following three elements (Ministry of the Environment 2004b):

- Environmental conservation cost: cost and investment for prevention of occurrence of environmental burden
- Economic effect accompanying environmental conservation: profit gained by a company as a result of environmental conservation
- Environmental conservation effect: environmental profit from avoidance or control of environmental burden

That is, environmental accounting is usually conducted for each measure or project to perform cost-benefit analysis of economic activities at the corporate level and add up the results. It differs greatly from financial accounting in that, of the above-described three elements, the environmental conservation effect is expressed in a quantitative unit (Ministry of the Environment 2004b). Although it takes a lot of labor for a company to calculate the reduction amount of an environment damaging substance, the result of calculation cannot be directly compared with the environmental conservation cost expressed in the amount of money, because the two differ in dimension. If the environmental conservation effect can be converted into money, the effect on society can be directly compared with the direct cost, which is very attractive to the user. Some companies have already independently attempted to integrate and express environmental conservation effect (for example, Ricoh, Fujitsu, Toshiba, and Sanyo Electric). However, the methodology differs among the companies, and the results are not consistent with each other. According to the Environmental Accounting Guidelines issued by the Ministry of the Environment, although environmental conservation effect should be expressed quantitatively in principle, economic assessment can be used according to purpose. In addition, the Guidelines explain LIME and other environmental economic assessment methods.

Kyoto City (2007) conducted environmental accounting for waterworks and sewerage sites. LIME was used for the assessment of environment conservation effect. Table 0.2-7 shows the results of the assessment. When environmental conservation effect is assessed for environmental accounting, the amount of environmental burden reduction from the previous fiscal year is often calculated. In this research, the amount of environmental burden on the assumption that no measure is taken for environmental conservation is calculated as the baseline and is deducted by the amount of environmental burden in the fiscal year in question (when measures for environmental conservation are carried out) to calculate the potential reduction of environmental burden, which is then applied to LIME to conduct the economic assessment of the environmental conservation effect. As a result, it was indicated that, although the economic effect that accompanies environmental conservation cannot by itself fully recover the environment conservation cost, if the economic conservation effect is included in the assessment, the effect of reducing environmental impact can be fully expected on the whole.

Table 0.2-7: Environmental accounting carried out by the Waterworks Bureau of Kyoto City (Kyoto City 2007)

(Unit: thousands of yen)

Environmental conservation measures	Environmental conservation cost	Effect		
		Economical effect accompanying environmental conservation (internal economic effect)	Environmental conservation effect	Economic effect
Advanced process	747,886	-89,352	335,595	246,243
Restraint of environmental burdens, such as electric power reduction	28,621	198,501	14,361	212,862
Effective use of resources	301,443	415,159	13,888	429,038
Prevention of pollution during process	69,041	0	1,069,023	1,069,023
Other measures	56,490	0	7,210	0
Total	**1,203,481**	**524,308**	**1,440,077**	**1,967,166**

Although environmental conservation effect is usually expressed in quantity, effect in this table is the result of applying to the integration of LIME the decrease in the amount of environmental burden estimated on the assumption that environmental conservation measures are not taken. This enabled the direct comparison with environmental conservation cost and internal economic effect.
(Source) Waterworks Bureau of Kyoto City: Development of Methods for Assessment of the Environmental Conservation Measures by the Waterworks Project of Kyoto City [Report] March 2007

(2) Cost-benefit analysis

The object of environmental accounting is usually a business entity. The cost-benefit analysis of product life cycle is called life cycle cost-benefit analysis (LCCBA). The National Institute of Advanced Industrial Science and Technology (2007) cooperated with the electric and electronic equipment industry to develop LCCBA as an environmentally friendly design method by the full use of LCA and life cycle cost

(LCC). Figure 0.2-9 shows the result of LCCBA of a washing machine. This figure, where the vertical line indicates environmental impact and the horizontal line indicates the breakdown of cost, can be used for product design to improve each aspect effectively. For the purpose of this, a measure for saving water (introduction of a water circulation pump) and a measure for the chemical substance used for the base material (substitution with lead-free solder) were adopted. It was indicated that although the introduction of these scenarios increases the direct material cost, social benefit is large on the whole because the cost and environmental impact of water supply and purification are reduced and the reduction of environmental impact is expected at the time of disposal and recycling. As shown in Table 0.2-8, the final result of LCCBA is indicated in a form similar to the indication method for environmental accounting. This makes it possible not only to confirm changes in the environment and costs, paying attention to each scenario for product design, but also to comprehensively verify the effect of improving the final product in the case of adoption of two or more scenarios. LCCBA has already been applied to some types of equipment, such as computers and copiers, and is expected to be firmed established in society as a tool for eco-design.

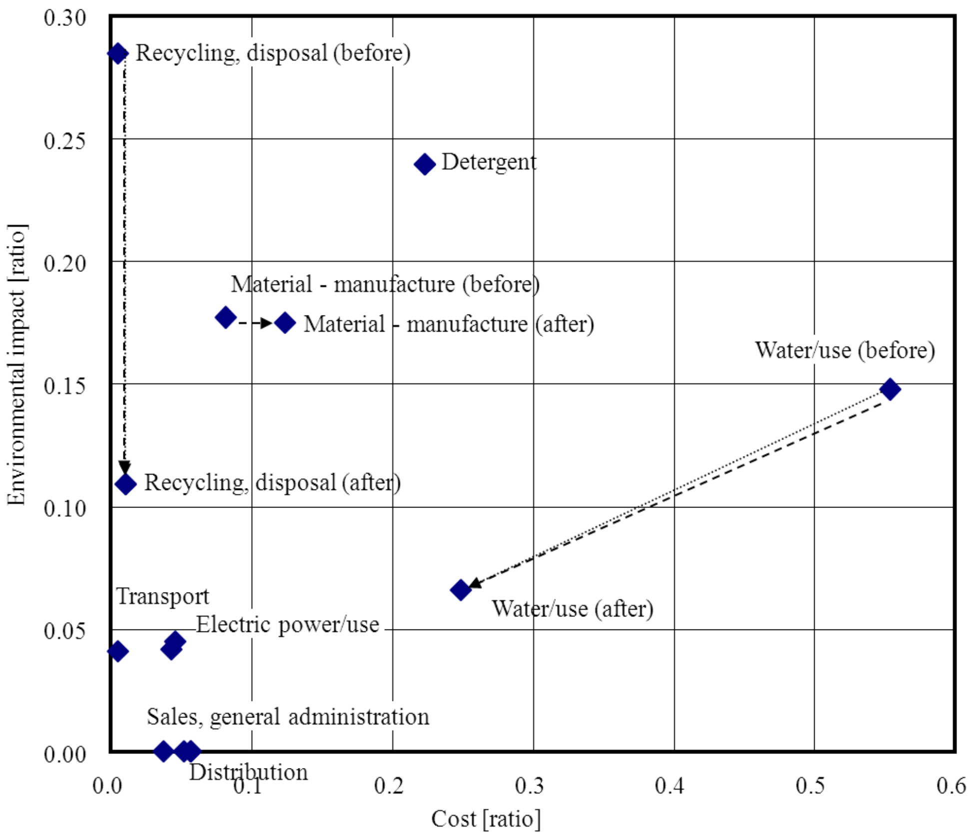


Figure 0.2-9: Assessment results of LCC and LCA on refrigerators (Yamaguchi et al. 2007)

A method to improve each aspect effectively is considered by showing environmental impact and cost. The environmental impacts of disposal and water consumption were improved greatly by the treatment of chemical substances and water saving measures. The water saving measures in particular had an effect on both environmental impact and cost.

Table 0.2-8: Arrangement of results of LCCBA on refrigerators

<table>
<tr><th rowspan="2">Measures</th><th colspan="2">Cost</th><th colspan="4">Effect</th><th colspan="2">Cost-effect</th></tr>
<tr><th colspan="2">Environmental conservation cost</th><th colspan="2">Environmental conservation effect</th><th colspan="2">Economic effect of environmental conservation</th><th>Effect–cost</th><th>Effect/cost</th></tr>
<tr><td rowspan="3">Water saving measures</td><td>Manufacturing cost</td><td>19,000</td><td rowspan="3">Reduction in environmental impact by water saving</td><td rowspan="3">1,800</td><td>Water charge</td><td>85,124</td><td rowspan="3">130,777</td><td rowspan="3">7.2</td></tr>
<tr><td rowspan="2">Planning/ development cost</td><td rowspan="2">2,000</td><td>Sewage charge</td><td>66,504</td></tr>
<tr><td>Electricity charge</td><td>-1,651</td></tr>
<tr><td>Chemical substance measures</td><td>Manufacturing cost</td><td>150</td><td>Toxic substance substitution effect</td><td>5,800</td><td colspan="2">-</td><td>5,650</td><td>38.7</td></tr>
<tr><td>Final product (Total)</td><td>Water saving and toxic substance substitution</td><td>21,150</td><td colspan="2">7,600</td><td colspan="2">149,977</td><td>136,427</td><td>7.5</td></tr>
</table>

Nippon Oil (2004) used LIME for the cost-benefit analysis of the development of a new product. The environmental burden of ENEOS Vigo, whose fuel efficiency was improved by combination with a friction modifier, is lower than that of the existing high-octane gasoline. The social effect of the change to ENEOS Vigo was estimated to be about 600 million yen on the basis of the sales in 2003. Moreover, it was indicated that the sale of low-sulfur light oil with less than 50 ppm of sulfur will cause a social effect equivalent to about 175 billion yen, as compared with the existing light oil. This greatly exceeds 6.6 billion yen, the amount of investment in the equipment for production of the product.

(3) Full-cost assessment

In environmental accounting and cost-benefit analysis, assessment is made by the difference between the cost of reducing environmental impact and the benefit from the reduction. In contrast, full-cost assessment (FCA) is based on the total of internal cost, which the company in question pays during product life cycle, and external cost, which is depletion of a specific value not on the market (UNEP 2001) (Figure 0.2-10). The cost of a product developed to reduce environmental burden may be higher than the cost of the existing product because of scale of manufacture or immature skill. Because FCA can count reduction in environmental impact, a characteristic of an environment-oriented product, it is possible to discuss the trade-off relation between the disadvantages of cost rise and the advantages of social cost reduction. Here lies the highest significance of the introduction of FCA.

Figure 0.2-11 shows the calculation result of FCA of refrigerators: a refrigerator that uses a specified CFC (old products) and a refrigerator that uses an alternative CFC (new products) (Itsubo et al. 2003). Both refrigerators' LCC were about three to four times the social cost. Because the specified CFC has a high heat of vaporization, the power consumption of the refrigerator using the specified CFC is low. However, because the specified CFC strongly absorbs infrared rays and destroys the ozone layer, it causes a great environmental impact during radiation. On the other hand, because the alternative CFC has a relatively low heat of vaporization, the power consumption of the refrigerator using the alternative CFC is high. Therefore, the cost of using the refrigerator is high. However, because of the high speed of decomposition in the air, contribution to the greenhouse effect and the ozone layer destruction is lower than in the case of radiation of the specified CFC. Because these tendencies were reflected in this case, the new product's LCC was higher than that of the former product, while the former product's social cost was higher than that of the new product. In addition, the new product's overall cost was estimated to be lower than the former product's. This means that the effect of reducing the social cost by the change to the alternative CFC is larger than an increase in the internal cost.

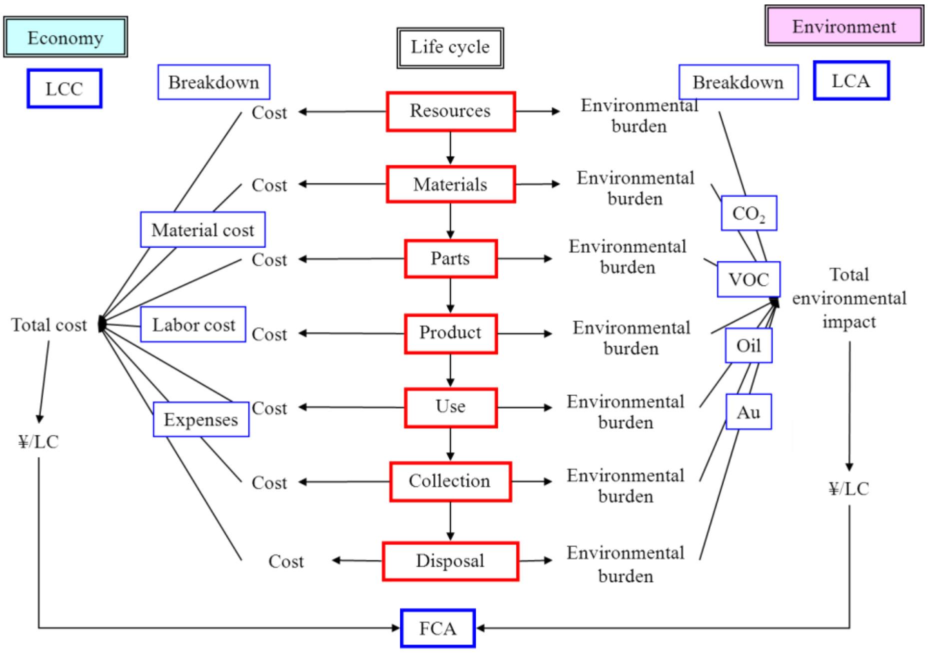


Figure 0.2-10: Concept map of FCA

Total cost is assessed based on the total of the internal cost calculated by LCC and the external cost calculated by LCIA.

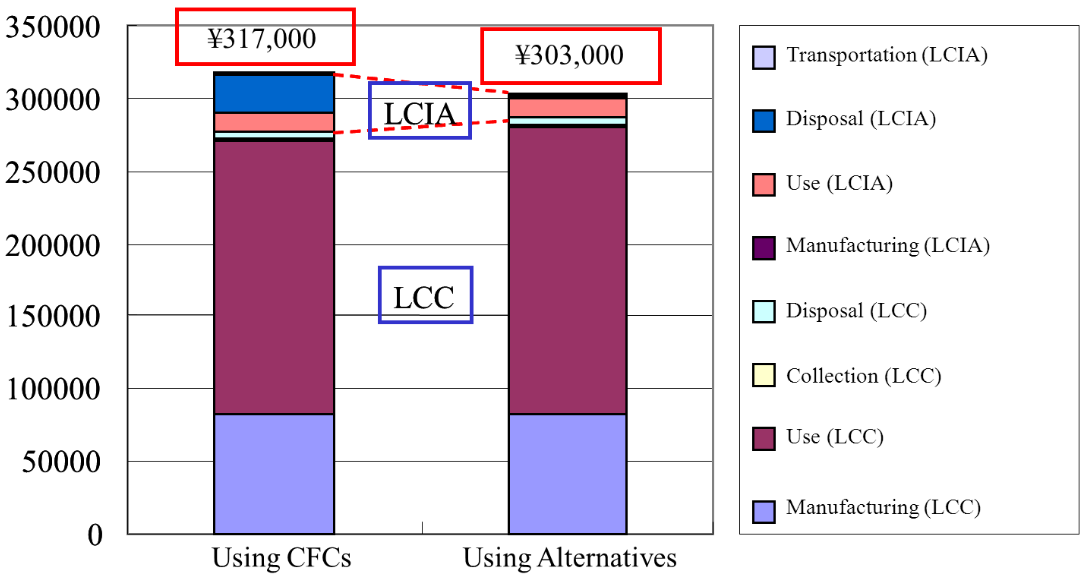


Figure 0.2-11: Result of full-cost assessment on refrigerators

Because cooling efficiency lowers when a specified CFC is replaced with an alternative CFC, the cost of use increases. However, because great reduction in environmental impact at the time of emission is highly effective for reducing external cost, the overall cost lowers.

When environmental issues are discussed from the viewpoint of economics, the internalization of the external cost is often taken up. FCA has been regarded a quantitative practice of the internalization.

(4) Material flow cost accounting

Material flow cost accounting (MFCA) is a method for grasping the economic size of waste from plants by measuring the flow and stock of manufacturing materials by quantity and amount of money and calculating the cost of waste as a negative product (Kokubu et al. 2006). MFCA makes it possible to measure the economic value of waste produced during each process of manufacture and to obtain measures for more effectively making efforts, such as the improvement of manufacturing quality and the improvement of the yield ratio (Figure 0.2-12). Since FY1999, the Ministry of Economy, Trade and Industry has regarded MFCA as an effective method for making the environment and economy consistent with each other and has supported the development of this method and its introduction to companies. As of FY2005, MFCA had been used by 45 companies, mainly in the processing industry.

The reduction of waste leads to the reduction of raw material cost and waste disposal cost. At the same time, the effect of reducing environmental impact is expected through a saving of resources consumption and reduction of waste. If MFCA is fused with LIME, both of the above-described effects of waste reduction can be expressed by economic indexes. So far, some companies, such as Tanabe Pharmaceutical and Sanden, have conducted research on the fusion.

Figure 0.2-13 shows the assessment results of the MFCA and LCIA conducted by Canon. This figure shows the interrelation between the MFCA value related to negative products and the environmental impact by LIME before and after process improvement. It was confirmed that polyol and stainless produced as waste can be reduced through the improvement of the processing process and that environmental impact can be reduced through reduction of consumption of exhaustible resources and fossil fuels and reduction in the volume of landfill waste.

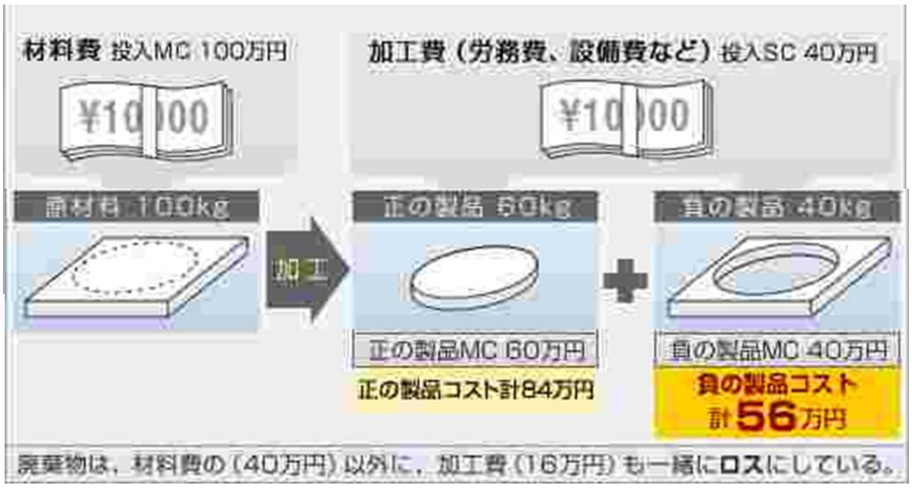


Figure 0.2-12: Concept map of MFCA (JMA Consultants, Inc. 2007)
The economic value of loss is visualized as a negative production cost by including the cost of waste.
Portions where loss is great are clarified by assessment of a series of processes,
and effective reduction measures are selected based on the clarification.

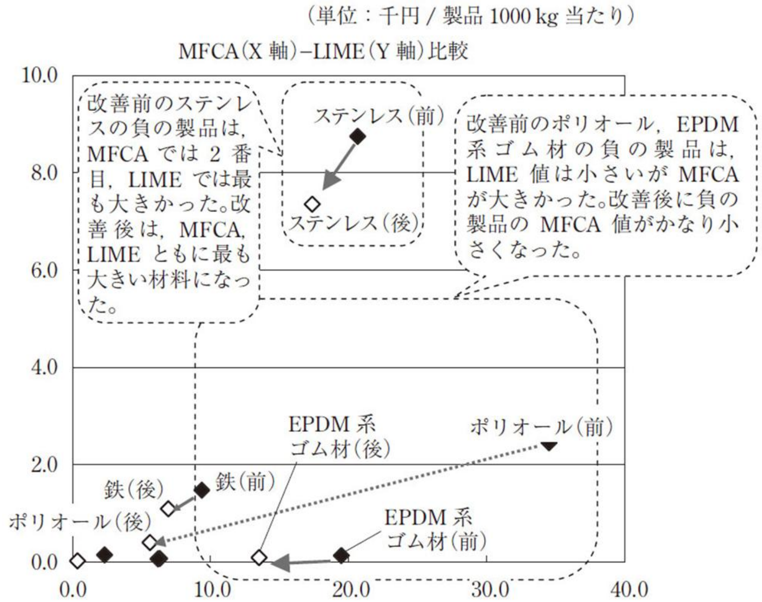


Figure 0.2-13: Case of assessment that fuses MFCA with LIME (JMA Consultants, Inc. 2007)

A company reduces costs and environmental impact at the same time by improving the manufacturing process and reducing the amount of waste materials.

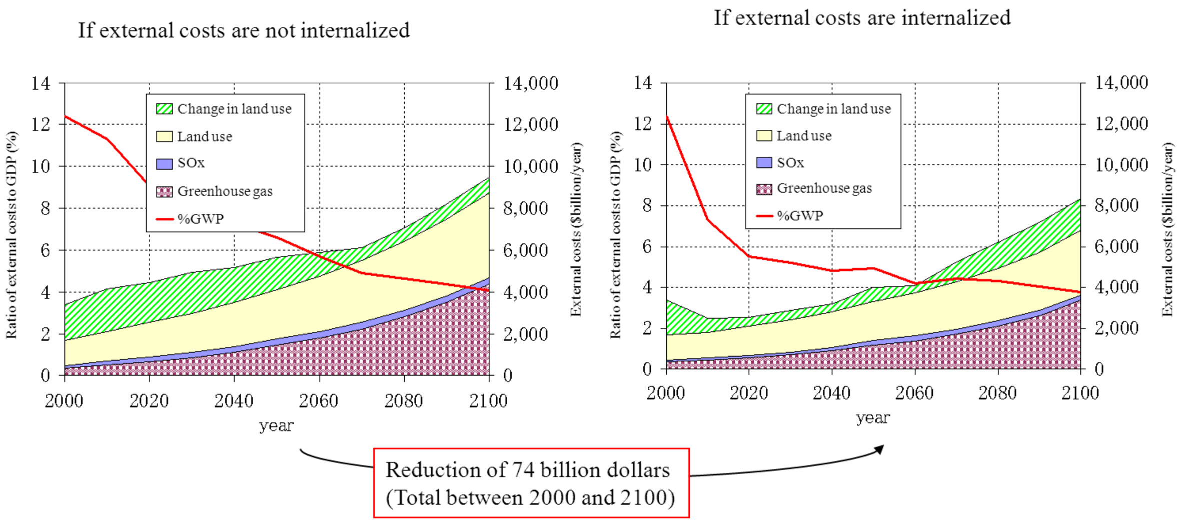
0.2.4 Green GDP, sustainability indexes

In 1987, the Brundtland Committee established in the UN proposed the concept of "sustainable development" as development that fulfills the current generation's needs without damaging the future generation's needs. The UN's Millennium Ecosystem Assessment pointed out that human activities' imposition of stress on the ecosystem has been increasing and there is the danger of failing to support the sustainability of future generations. Although the concept of sustainability has already existed in this way, it has drawn special attention in the recent years when global warming and other environmental problems have been widely recognized as urgent issues. The basic concept of sustainability is intergenerational fairness. Because of this, mid- and long-term indexes and assessment are needed to measure the degree of intergeneration fairness.

With regard to discussions as to what social system will enable sustainable development, increasing attention has been paid to economic discussions based on the facts and recognition of changes in the global environment and the limitations of resources. The internalization of external diseconomies caused by environmental impact, which was proposed by Pigou, is regarded the idea that will become the core of environmental economics. Daly pointed out that since GDP contains not only qualitative increase (development) but also quantitative increase (growth), it is problematic to use GDP for the definition of sustainability.

Under this situation, various indexes have been proposed concerning sustainability. The genuine progress index (GPI) and the System of Environmental-Economic Accounts (SEEA) were proposed as revised GDP indexes, from which the depletion of natural capital not included GDP in is deducted. However, this is used for annual assessment at the national level, not for mid- and long-term assessment.

An example of what is used for sustainability assessment by the use of LIME is the simulation of optimal economic development in the whole world until 2100 carried out by Tokimatsu et al. (2006). The simulation used the graphics programming environment (GRAPE), an integrated assessment model (IAM) that interrelates macro economy, energy systems, land use, emission of greenhouse effect gas, and climate changes, for calculating the amount of environmental burden in ten regions in the World dynamically and applying it to LIME's integration factors to calculate the social cost in the whole world. Moreover, the result was deducted from total GDP in the whole world to assess social sustainability. As a result, it was indicated that the external cost will increase 2.5 times to 8 trillion yen at the end of this century, and global warming and land use (maintenance and alteration) in particular will have great impact (Figure 0.2-14). Moreover, it was indicated that although the internalization of the external cost will decrease GWP, compared with the case where the external cost will not be internalized, the internalization will lead to forest conservation and saving of fossil fuels (Figure 0.2-15).



About three times the whole world's GDP (GWP: $28 trillion)

Figure 0.2-14: Result of prediction of long-term environmental impact by fusing LIME into IAM

The introduction of measures that internalize external costs enables a great reduction in environmental impacts.

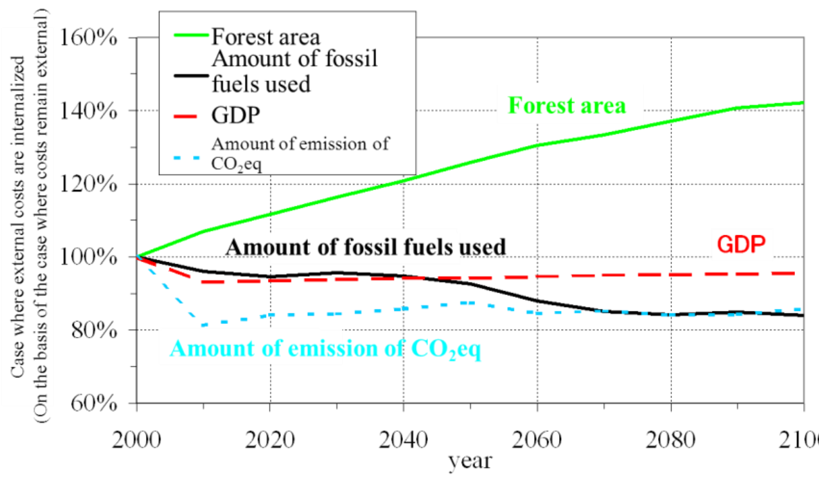


Figure 0.2-15: Changes in forest area, the amount of emission of greenhouse gas, and Gross World Product by the internalization of external costs

Although the internalization of external costs reduces economic value by about 5%, it promotes forest conservation and reduction in the emission of greenhouse gas.

Column 0.2-2

Integrated assessment models (see Kurosawa 2007)

The influence of global warming extends all over the world, and the causes and measures affect energy, agriculture, and the whole economic system. From 1990, model development was promoted to consider comprehensive measures against the environmental problems that accompany global warming. Models should have the following characteristics:

1) Inclusion of various elements, such as the mechanism of climate changes, energy, land use, influence of climate changes, and economy
2) Capacity to predict long-term influences, ranging from emission of greenhouse effect gas to environmental impact
3) Simultaneous treatment of top-down ways of thinking about environmental policies and others and bottom-up approaches to production activities and technological development

Because, in this way, models need comprehensive assessment in terms of time, space, and interdisciplinary fields, they are called “integrated assessment models.”

Most of the recent integrated assessment models deal with CO_2 as a greenhouse effect gas. Assessment reports issued by the Intergovernmental Panel on Climate Change (IPCC) also explain the backgrounds to the models and the results of assessment by the use of the models. In addition, since 2000, integrated assessment models that deal with types of greenhouse effect gas other than CO_2 have been developed. As a result, it became possible to discuss the six types of greenhouse effect gas specified in the Kyoto Protocol, combining long-term reduction measures appropriately.

Various integrated assessment models have so far been developed or proposed. Famous ones are DICE developed by Nordhaus (2000), FUND developed by Tol (2002), and PAGE used by Stern (2007). In Japan, AIM and GRAPE (Kurosawa) have constructed original integrated assessment models.

For example, Stern assessed long-term economic impact of global warming by the use of an integrated assessment model (Figure 0.2-A). According to the result, if external costs, such as health impact, and the impact of large-scale disasters are included, the economic impact of warming will exceed 10% of GDP at the end of the 22nd century. On the other hand, Stern pointed out that because the cost of controlling the emission of CO_2 is sufficiently low, it is important to carry out measures against warming early.

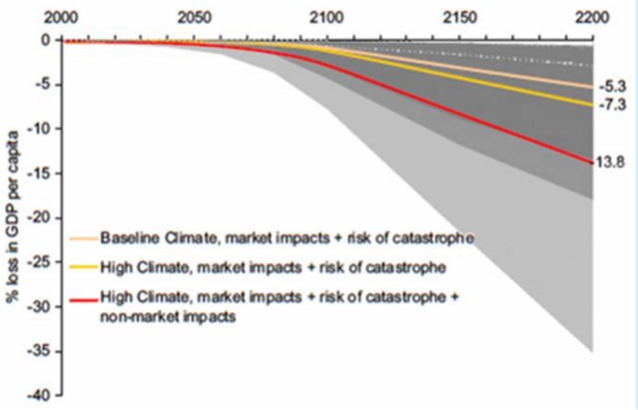


Figure 0.2-A: Result of assessment of global warming’s impact on economy by the integrated assessment model (Stern 2007)

If social and other costs are included, the impact of global warming will exceed 10% to 30% of GDP at the end of the 22nd century.

0.3 Conclusion

This chapter, as an introduction, explained trends in LCIA research and the main use of LIME. LCIA research, which became full-scale in the 1990s, developed into an interdisciplinary research field after 2000. Research on the development of LIME methods greatly contributed to the improvement of the level of LCIA research. The UNEP/SETAC Life Cycle Initiative arranged the current situation of LCIA research, referring to LIME, and has been recognized as a method that is internationally leading LCIA research.

With the securing of the international presence of LIME, LIME has been used for LCA case studies in various ways. For example, there are many cases of assessment that pay attention to environmental problems closely related to each product, such as indoor air contamination by construction materials, land use by farm products, air pollution by automobiles, and biological resources by paper. In addition, technological improvement has made it possible to assess environmental improvement effect without overlooking important environmental impact because of comprehensive grasp of environmental impact.

Because LIME is designed to assess environmental impact on the premise of the acquisition of inventory data, it has already become possible to use LIME beyond the framework of LCA. In reality, LIME has already begun to be used for various methods, such as environmental efficiency, factors, environmental accounting, LCCBA, MFCA, and green GDP. In conjunction with this, LIME is used for measuring not only the environmental performance of products but also that of companies. Moreover, recently LIME has been used for assessing the prediction of environmental impact, fusing with an integrated assessment model. In the future, LIME is expected to be used for considering sustainability, together with social impact assessment.

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