JLCA NEWS ENGLISH EDITION Nov.2014

No.18

JLCA NEWS LETTER

Life-Cycle Assessment Society of Japan

LIME2

Life-cycle Impact assessment Method based on Endpoint modeling

Chapter 2 : Characterization and Damage Evaluation Methods

LIME2

Life-cycle Impact assessment Method based on Endpoint modeling

Chapter 2
Characterization and Damage Evaluation Methods

2.10 Land use
2.11 Resource consumption
2.12 Waste
2.13 Noise (Road Traffic Noise)

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Chapter Ⅱ

Characterization and Damage Evaluation Methods

Contents

Chapter II

Characterization and Damage Evaluation Methods

2.10 Land use

Changes in LIME2

- Uncertainty assessment of damage factors was carried out. Uncertainty includes geographical variability (uncertainty about at what point the land use entered in the inventory is assessed).
- When damage factors for primary production were calculated, the Chikugo model, which is used for estimation of potential net primary production (NPP) of land, was changed into an equation more suitable for Japan.
- Assessment cases were added concerning an increase in the extinction risk of vascular plants in the field of land development, which is a basis for the calculation of damage factors to biodiversity.

2.10.1 What phenomenon is the environmental impact of land use?

Roughly speaking, because most human activities are carried out on land, all of them are land use activities. Because the area of land and the area of inhabitable land in Japan are small compared with the population, competition in land use is likely to become a basic cause for various environmental problems. Therefore, the viewpoint of land use is extremely important.

In the framework of LCA, The release of substances generated from human activities into the air, water, and soil (basic flows) is measured (classified) in each impact category, such as global warming and toxic chemicals. Among the phenomena that are not covered by the other impact categories, those directly or indirectly generated by a change in land surface or the maintenance of an unnatural state are covered by the impact category of land use – putting it simply, the destruction and loss of nature that accompany land development.

(1) Causal relationship between land use and environmental impact

In Japan, if a project is accompanied by land transformation and is large in scale and has considerable environmental impact, the legislated mechanism of environmental impact assessment (EIA) is applied, under which the implementing body should survey, predict, and assess the environmental impact of the project beforehand and have the results reflected in the project as environmental conservation measures and the like (Terada 1999). What are useful for grasping the environmental impact of land use are technical guidelines and manuals concerning environmental assessment and information on existing cases of environmental assessment. Concretely, such documents and information make it possible to find the following channels for the environmental impact of land use (Figure 2.10-1).

The destruction of land surface gives direct damage to the ecosystem (the extinction of individual animals and plants and the disappearance of living and growing spaces due to changes in land). If surrounding areas are not transformed directly, they receive indirect impact from drying and changes in the sunshine condition. In addition, if a habitat is divided, resulting in isolation or reduction, the quality of the ecosystem will decline. In the case of animals that move across a wide area, a change in the inhabitation conditions related to feeding and nesting may have impact. Such indirect impact will continue to exist throughout the period when land transformation is maintained.

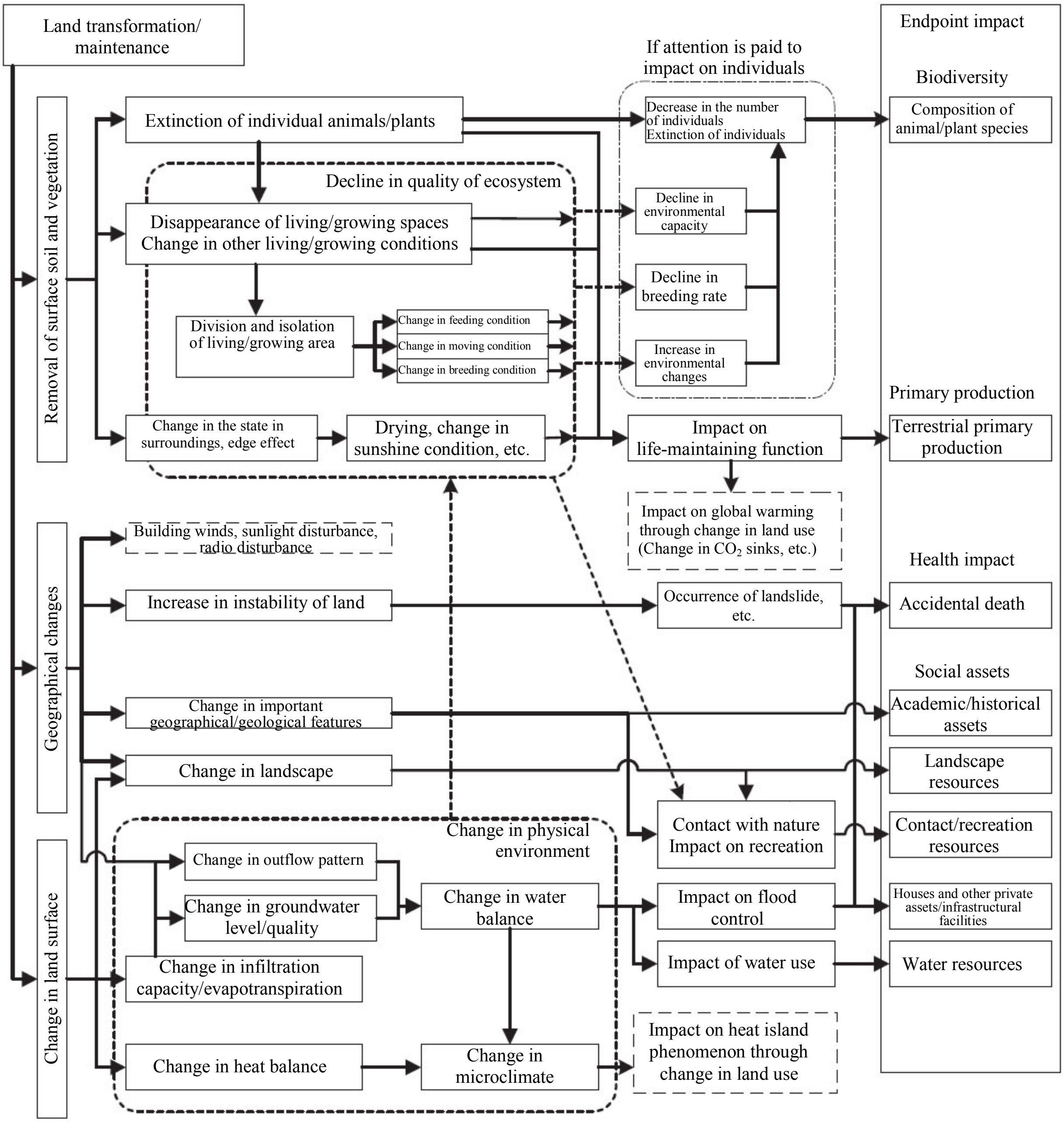


Figure 2.10 -1: Causal relationships among environmental impacts of land use

As impacts directly received by human society, land transformation may change landscape or academically or historically important geographical/geological features or give trouble to activities for having contact with nature or recreation activities. If instability increases in a landslide area, the possibility of occurrence of a disaster will increase. In addition, if measures against removal of vegetation are insufficient, rainfall during construction may cause the inflow of muddy water into surrounding water areas, or a change in the outflow pattern after construction (at the stage of using land) which has in turn has impact on the ecosystem, flood control, and water use through a change in water balance. Moreover, land use may have impact on microclimate, such as the heat island phenomenon. Although forests are expected to contribute to global warming measures as CO2 sinks, their disappearance due to land transformation may contribute to an increase in CO2 emissions.

(2) Endpoints of environmental impact of land use

The environmental impact of land use does not give direct damage to the endpoints. Therefore, we will outline the endpoints' relationships with land use.

a Impact on the ecosystem

Japan's national biodiversity strategy (Council of Ministers for Global Environment 2002) roughly divides the biodiversity crises into three from the viewpoint of the current situation and problems of biodiversity. The first crisis is "reduction or disappearance of living or growing areas through a decrease or extinction of species directly caused by human activities or development or the destruction, division, or deterioration of the ecosystem." At present, many animals and plants in Japan are facing a crisis of extinction. The following are the main causes for a decrease in the number of species: overhunting, illegal digging, excessive gathering for an ornamental and commercial purpose; destruction of living or growing areas through development or land use; and worsening of living or growing environments.

With regard to plant species (vascular plants) in Japan, for example, if deforestation is included in land use, land use accounts for half of the causes for facing a crisis (Figure 2.10-2).

In Japan, a basic survey for conservation of natural environments that is generally called the "Green National Census" has been carried out continuously. With regard to vegetation, the 5th survey (Ministry of the Environment, Nature Conservation Bureau 2004) reported that about 440,000 ha, 1.28% of the green area (0.26% per year), was transformed during about five years between the late 1980s and the early 1990s.

In terms of natural grade of vegetation, 2.19% of the secondary grassy plains (plains with high grass) at a grade of 5, and 1.73% of the secondary forests at a grade of 7 were transformed.

With regard to primary production, the 1st basic survey for conservation of natural environments (in FY1973) (edited by the Environment Agency 1976) examined the "current amount of vegetation," the amount of plants in the Kanto region, and the "vegetation production volume," the annual amount of organic substances produced by the plants. With regard to the relation between production volume and the social environment, the relation with population was analyzed and the result of regression analysis showed that an increase in population density by 1 [person km-2] results in a decrease in the production volume by 50 [kg km-2 yr-1]. Based on the result of consideration under LIME, the actual primary production volume has been estimated to be less than 50% of the potential primary production volume in Tokyo, Osaka, Kanagawa, and other prefectures.

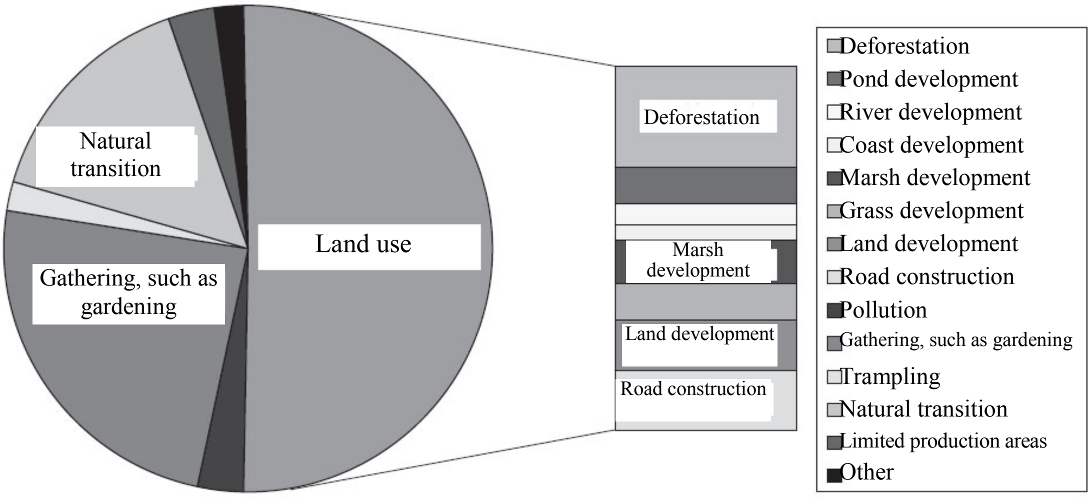


Figure 2.10-2: Causes for decrease in vascular plants

Result of counting of top three items of causes for decrease according to the Red Data Book (edited by the Environment Agency 2000)

b Human health

Figure 2.10-3 shows the number of dead and missing persons due to recent natural disasters. Except in 1993 and 1995, when the Southwest-off Hokkaido Earthquake and the Great Hanshin-Awaji Earthquake occurred, dead and missing persons due to wind and flood disasters, including avalanche of rock and earth, and snow disasters occupied a large proportion. For example, around the middle of September 2000, autumn rain front and typhoon No. 14 caused heavy rain, resulting in many deaths around the Tokai region.

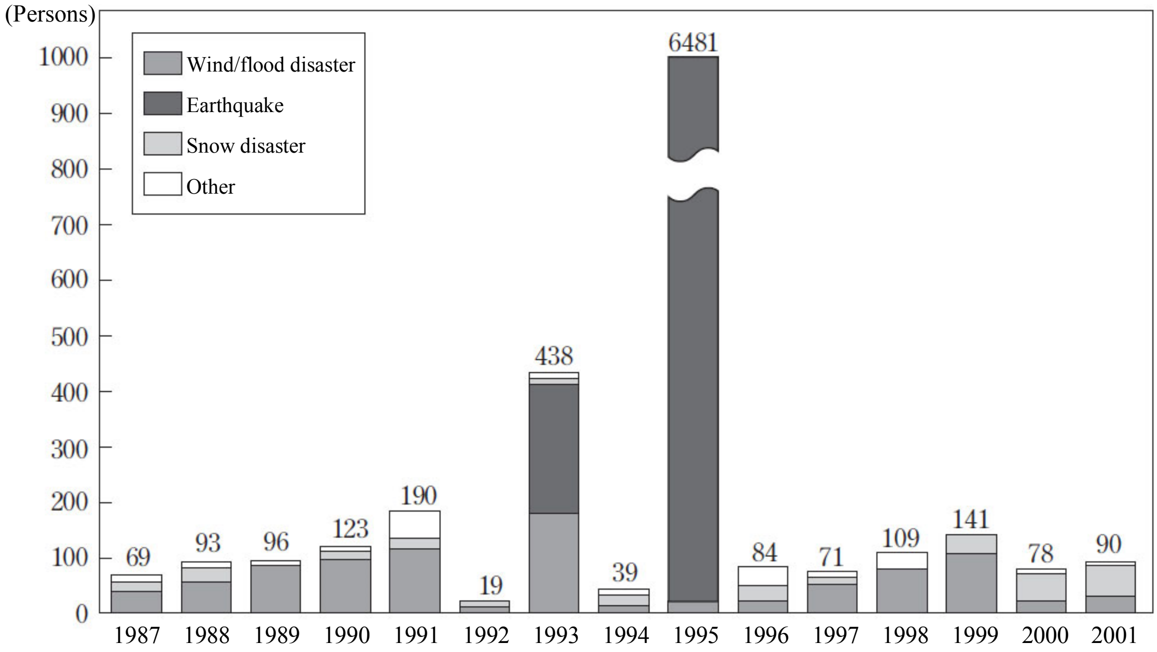
According to the White Paper on Disaster Management (edited by the Cabinet Office 2003), because Japan not only has many steep mountains, valleys, and cliffs as well as frequent earthquakes and volcanic activities, but also is prone to be struck by typhoon, heavy rain and heavy snow, sediment disasters such as avalanche of rock and earth, landslide, cliff failure are likely to occur. Also, because of the recent “changes in land use,” such as progress in the urbanization of forest land, hilly land, and their surroundings, sediment disaster victims occupy a large proportion of the total number of natural disaster victims.

c Influence on social assets

If a paddy field in a river basin is transformed into a housing site, the field’s function to reserve and infiltrate rain water will decline. As a result, if the amount of precipitation is the same, the amount of outflow increases. Because of this, flood has recently been frequently caused by a small amount of precipitation. This is called urban flood damage.

In addition, progress in urbanization in areas where flood can occur when a river overflows (flooding area, inland water area) means accumulation of assets that may receive damage.

In this situation, it has been pointed out that, in spite of a decrease in the inundated area, the amount of damage has been increasing (Figure 2.10-4).



Notes) The Cabinet Office created this graph based on the Fire Defense Agency's data. Earthquakes include tsunami disasters.
Of the deaths in 1995, those due to the Great Hanshin-Awaji Earthquake include 912 indirect deaths.

Figure 2.10-3: Number of dead and missing persons by type of disaster

•Reprinted from the White Paper on Disaster Management 2003 (edited by the Cabinet Office 2003).
•Although the proportion of sediment disaster victims was about 80% of the total number of natural disaster victims in 1984, it has been around 50% since then (edited by the Cabinet Office 2003).

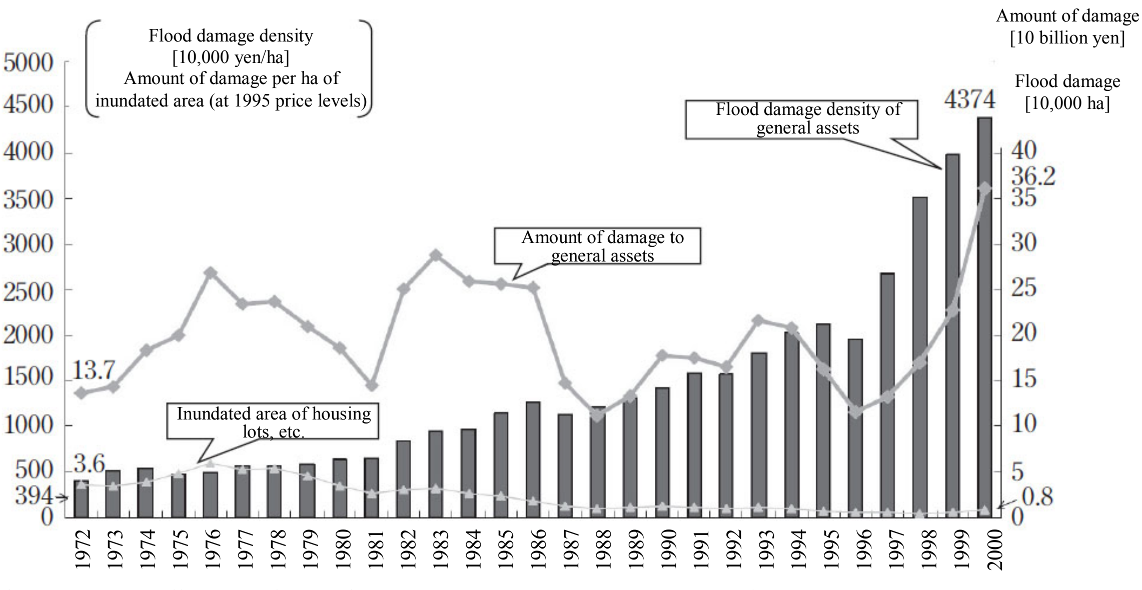


Figure 2.10-4: Changes in the inundated area and the amount of damage to general assets

•Reprinted from "Aiming for Planning of Creation of Sound Water Circulation Systems" (Ministerial Liaison Council on Creation of Sound Water Circulation Systems 2003) (source: River Bureau of the Ministry of Land, Infrastructure, Transport and Tourism)
•In spite of a decrease in the inundated area, the amount of damage has recently increased, which indicates that floods peculiar to urban districts have frequently occurred.

2.10.2 Characterization of land use

(1) Characterization factors of existing land use

Table 2.10-1 shows a conceivable approach for characterization factors of land use. There is another approach whereby methods that assess land function and primary production of plants are classified into the same type, because they assess the life-maintaining function (Udo de Haes et al. 2002).

Among them, the approach that can actually present quantitative and universal impact assessment factors for the purpose of application to LCA at present is limited to "indexing of biodiversity or the life-maintaining function." Table 2.10-2 shows the characteristics of the methods associated with this approach.

Table 2.10-1: Approaches conceivable for impact assessment of land use

Policy	Outline
(1) No weighting	Characterization is made by simply adding up transformed area and/or maintained area × time, irrespective of the type of land use. Although this is simple and clear, because transformation and maintenance cannot be integrated, the characterization result is indicated as two subcategory indices. Alternatively, either transformation or maintenance is selected.
(2) Classification of the ecosystem and weighting by panel	The ecosystem is divided into some classes according to quality. If an area is transferred from a class to another class because of land transformation, it is indexed as inventory – by applying the weight of each class, as the case may be. The panel method is applied to the weighting. In Japan, the degree of natural vegetation is well known as a method for classification of the ecosystem. Tadaki (1998) suggests a quantitative impact assessment method by the use of the degree of natural vegetation, although this is not intended for application to LCA. In addition, a report was made about the development and application result of a method for jointly grasping, for each degree of natural vegetation, the transformed areas of three categories divided from the viewpoint of the ecological network in order to assess the impact of natural land transformation for industrial activities on the ecosystem (Goto 2001).
(3) Function of land (assessment based on two or more items or a hierarchical assessment item system)	Baitz (1998) suggested characterization factors that take into consideration eight land functions, such as purification of pollutants and prevention of disasters. Because each function greatly differs among development areas, they cannot be used for general purposes at present. However, they are expected to become widely applicable in the future by the use of the geographic information system (GIS). In Japan, although application of LCA is not intended, there are the following examples: Tadaki suggested a quantitative (impact) assessment method based on the panel assessment of 12 environmental conservation functions (1998) and performed trials about it (2002); Ito et al. (1993) classified green spaces' environmental conservation functions into three divisions and six items and created an analysis support system for Zushi City. This system has been used for setting environmental conservation objectives and for carrying out the system for environmental impact assessment of development products under the City's ordinances.

(4) Indexing of biodiversity or the life maintaining function	As an impact assessment method for biodiversity to apply it to LCA, Müller-Wenk (1998), and Lindeijer et al. (1998) and Köllner (2000) suggested a method whereby the ratio of endangered species and the density of species generated by land use, respectively, are used as the index of biodiversity. Based on the early researches by Müller-Wenk (1998) and Köllner, Goedkoop (2000) suggested a method that uses changes in the density of species as the index. As the assessment index, Weidema et al. (2001) suggested the product of the following three indices: species richness (SR), ecosystem scarcity (ES), and ecosystem vulnerability (EV). By using the combination of this suggestion (Weidema et al. 2001) and earlier research (Lindeijer et al. 1998), Lindeijer (2002) mainly examined case studies on construction materials. As the index of the life maintenance function, Lindeijer et al. (1998, 2002) and Weidema et al. (2001) used net primary production (NPP) (or a similar index). Under LIME, a method to assess loss of the existing vegetation NPP was developed as an assessment of impact on primary production, and a method to assess an increase in the extinction risk was development as an assessment of impact on biodiversity. The loss and the increase were adopted as damage factors (see 2.10.3).
(5) Land competition	Environmental impact means a decrease in remaining land by the use of natural land for a specific purpose on the assumption that land is a limited resource. Gulée et al. (2001) suggested land competition as a subcategory, assuming that land competition is an element of the impact of land use.

Table 2.10-2: Characteristics of the suggested methods for quantitative impact assessment by indexing of biodiversity or the life maintenance function

	Characteristics
Common points	• As forms of land use, impact is classified into that of transformation (conversion) and that of maintenance (occupation) to carry out assessment. • As the main elements that receive impact, attention is paid to biodiversity and the life maintenance function. • Among the types of biodiversity, the diversity of species is treated especially. • The object of assessment of impact on biodiversity is plants. • The goal is to show the impact assessment factor for each type of land use.
Differences	• There are a method whereby the results are shown separately due to limitations in the calculation method after classification into conversion and occupation and conduct of assessment (Lindeijer et al. 1998) and a method whereby the results are added up by introduction of the conception of recovery time (Köllner 2000) (the damage factor of primary production developed under LIME falls under the latter). • There are a method that includes areas that are adjacent to the directly used land and receive impact (Köllner 2000, Goedkoop et al. 2000) and a method that does not take neighboring areas into consideration (Lindeijer et al. 1998). The method developed under LIME falls under the latter. • As an index for assessment of the life maintenance function (primary production), Lindeijer et al. (1998) suggested “fNPP,” which does not take into consideration forests for farm products and lumber because they do not contribute to the natural ecosystem. In contrast, Weidema et al. (2001), Lindeijer et al. (2002) and the method developed under LIME adopted NPP, which includes farm products, etc. • Most of the methods that were suggested overseas and treat biodiversity as the object of assessment induce an index by weighting land according to the number of vascular plant species that can exist in a certain area (or the inclination of the relationship between the number of species and the area) and multiplying the result by time or area. Therefore, it is hard to say that the meaning as an endpoint index is not necessarily clear. The method developed under LIME treats endpoints and the result is an increment in the extinction risk. This index is clear in both the meaning

	and the calculation standards and is advantageous in that the damage factors are in the impact category of biotoxicity. • The area subject to impact assessment differs among cases. Müller-Wenk (1998) and Köllner (2000) covers Switzerland in principle, Lindeijer et al. (1998) covers the world, and Goedkoop (2000) covers Europe. LIME generally covers Japan.

Column 2.10-1

Product lifecycle and land use

LCA so far – especially, actual case studies – has hardly considered the aspect of land use. Therefore, this column will show why land use activities should be incorporated into LCA, taking industrial products as examples (Figure 2.10-A).

In the case of the development of a mine at the stage of gathering resources, because Japan imports many minerals and energy resources, land use not only in Japan but also in foreign countries should be taken into consideration as inventory at the stage of gathering resources. Next, lack of facilities for final disposal of waste at the stage of manufacturing has become an imminent problem.

Because information on land use has not been accumulated in a form usable for LCA, it is difficult to carry out LCIA of land use through the whole product lifecycle. Under LIME, therefore, consideration was given not only to the development of an impact assessment method but also to related inventory of land use in the impact categories of consumption of resources (Section 2.11) and disposal of waste (Section 2.12) as common and typical land use activities. As a result, for the convenience of those who carry out LCA, assessment factors that contain background data for construction of inventory of land use have been provided. Some of the LCA databases published recently (after the LCA project) contain information on land use as inventory data (Switzerland ecoinvent).

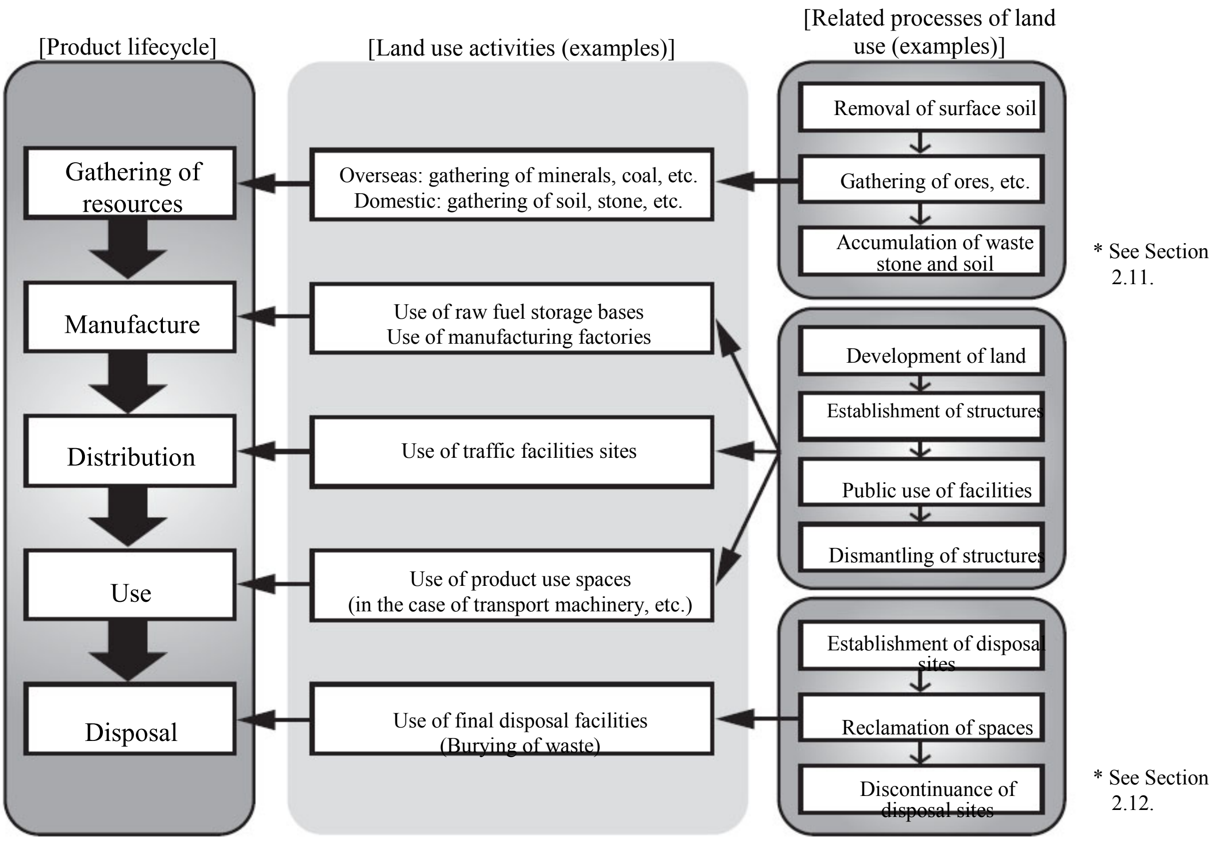


Figure 2.10-A: Land use processes related to product lifecycle

(2) Characterization factors of land use under LIME

At present, there is no globally-recognized approach as the characterization factor of land use.

Quantitative impact assessment by "indexing of biodiversity or the life maintenance function" is an attractive approach. However, it has the following disadvantages as the characterization factor: because the objects of assessment are limited to concrete ones, it is difficult to adapt as a comprehensive index of impact on various elements; calculated values have uncertainty (especially if maintenance and transformation are integrated); and there is no globally-recognized approach.

Among the other approaches, the "no weighting" approach cannot take land quality into consideration, but it is thought to be a comprehensive index that indicates potential impact. Therefore, calculated values are highly reliable. "Classification of the eco system and weighting by panel" remains semi-quantitative assessment, or the method to put together the classes depends on subjective assessment. The evaluation of "land function" requires a lot of information and cannot be put to practical use for LCA at present. Although "land competition" is a viewpoint to which attention should be paid, the method presented by Guinée et al. (2001) is the area of land used in the end.

Therefore, under LIME, taking into consideration the comprehensiveness and reliability of the index for indicating potential impact, we decided that transformation and maintenance should be divided as subcategories and recommended area as characterization in the case of transformation, and the simple multiplication of area and time as characterization in the case of maintenance. Each characterization factor is 1 (for equations, see 2.10.4.)

2.10.3 Damage assessment of land use

(1) Basic policy for calculation of damage factors

Figure 2.10-5 shows the basic framework of damage assessment of land use under LIME. With regard to the damage factors of land use, the basic policy is the same among the objects of protection, but the calculation procedure greatly differs among them. Therefore, this section only shows common bones. Details of damage functions and uncertainty assessment will be explained in the sections concerning primary production and biodiversity ((2) and (3) below).

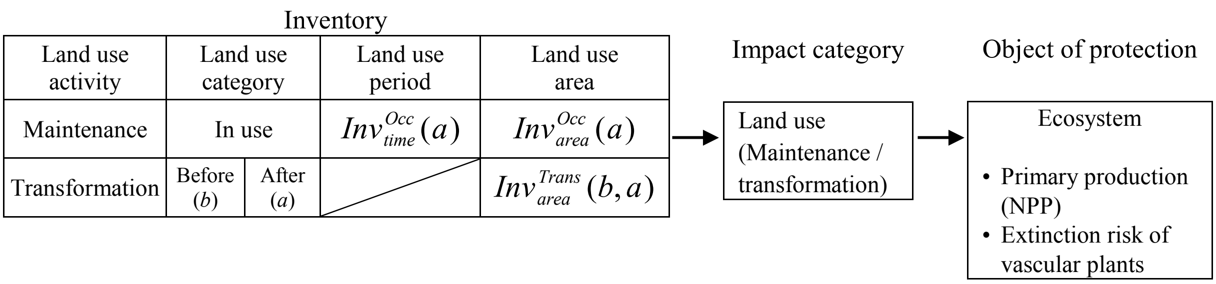


Figure 2.10-5: Framework of damage assessment related to land use under LIME

Column 2.10-2

Life cycle inventory of land use – concepts of transformation, maintenance, and area × time

Before the impact of land use is assessed, it is necessary to determine the form of measuring land use activities into inventory. We will explain the form by the use of Figure 2.10-B, picking up one of the related land use processes from Figure 2.10-A in Column 2.10-1 (for details, also see Column 2.10-3.)

As the inventory of land use, it is necessary to select a set of the following for each type: (1) area of land use; (2) period (time) of use; (3) form of land use (classification into forest, construction site, etc.) and activity (transformation, maintenance).

For the purpose hereof, we divided “transformation of land (change or conversion of land use)” from “maintenance of land (occupation of land).” The former is an act of changing the state of land division (land use classification), while the latter is an act of keeping the condition of land to carry out activities for achieving the purpose. Because the period of transformation is usually far shorter than the period of maintenance, inventory can be simplified by omitting the measurement of time and paying attention only to changes in the form of land use (division).

Such a form has been usually used for the impact assessment method of land use overseas (Udo de Haes et al. 2002). Because the environmental impact of land use is highly regional, it seems desirable to become able to include the location of land use in the inventory in the future (see Column 2.10-6).

In addition, if the ecosystem is restored after being damaged, it seems necessary to include the result in assessment. In this case, it seems appropriate to include positive restoration activities in the inventory as transformation that brings about good results. If related positive and negative processes are measured expressly to the extent possible, the transparency of LCIA will improve and it will be possible to properly reflect environmental conservation efforts in the assessment.

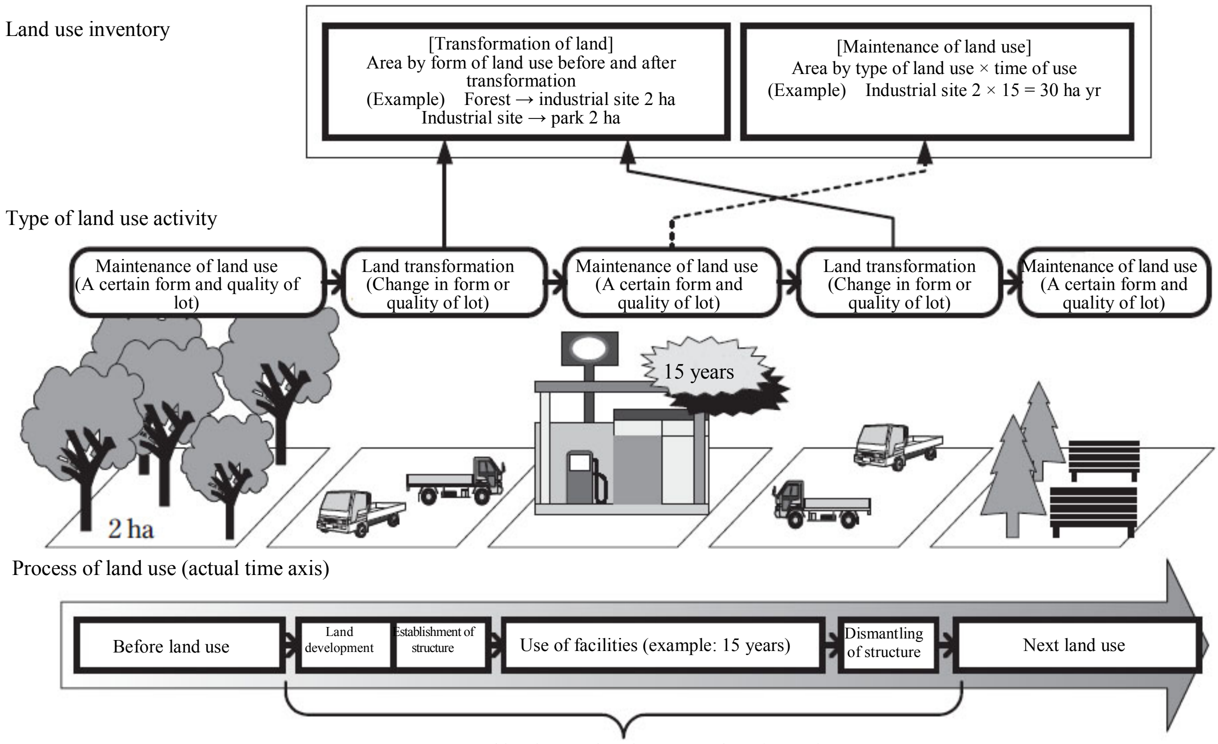


Figure 2.10-B: Product lifecycle and related process of land use

Column 2.3-10

Points that need attention concerning land use inventory
(1) Maintenance: non-separability between area and time **(Udo de Haes et al. 2002; Goedkoop et al. 2000)** Actual product LCA assesses the function performed by a unit of a product, for example. In this case, if 30,000 units of the product are manufactured in 15 years at an industrial site (2 ha) in Figure 2.10-B, how much land use area and time are needed for a unit of the product? If 2,000 units (30,000/15) are manufactured in a site of 2 ha every year, a unit of the product occupies 0.001 [ha] (2 [ha] ÷ 2,000 [units]) per year. From another viewpoint, a unit of the product occupies 1/15,000 [ha] (2 [ha] ÷ 30,000 [units]) for 15 years. In this way, the number of combinations that relate area and time to function unit is infinite concerning the process of maintaining land use. However, from the viewpoint of area × time, it is fixed at 0.001 [ha yr] under both ways of thinking. Because of this, for the purpose of the land use inventory under product LCA, maintenance is measured by the unit of area × time. **(2) Transformation: What process is responsible from the past to the future? Problem of allocation of transformation** **(Udo de Haes et al. 2002), (van der Voet 2001), (Guinée et al. 2001)** If a naturally transformed site is used continuously by the same process, is it necessary to include the past transformation in the inventory? If so, the amount of land use transformation should be allocated among the past processes related to the site. In addition, because land does not disappear, it is necessary to allocate it to future processes. However, this is impossible to carry out. On the other hand, there is the assertion that it is all right to allocate it only to the initial land transformation process. Because this view is the same as "consumption of natural resources should be allocated only to the initial use process, but not to the recycling process," it is called "land recycling." However, if a road site used for transportation of a product was transformed in the past, is it completely unnecessary to include this in the inventory? With regard to LCA of land use, there remain many points to be clarified at the stage of inventory construction.

Table 2.10-3: Category endpoints of land use and objects of calculation of damage function

Object of protection	Category endpoints		Objects of calculation of damage function	
Human health	Direct death/injury	Death/injury by disaster	×	Quantitative impact assessment is difficult. Preventive and other measures are taken.
Social asset	Academic & historical assets	Destruction of important topography and geography, etc.	×	Poor quantitative information

	Landscape resources	Loss/deterioration of landscape assets, reduction in viewable range, etc.	×	Quantitative impact assessment is difficult.
	Contact/recreation resources	Loss/deterioration of contact with nature, recreation resources, non-accessibility, etc.	×	Poor quantitative information
	Houses and other private assets, infrastructural facilities	Landslide, loss of houses by flood, inundation, etc.	×	Quantitative impact assessment is difficult. Preventive and other measures are taken.
	Water sources	Fall of level of well water, decline in river base flow, such as muddiness, etc.	×	Preventive and other measures are taken.
Primary production	Terrestrial ecosystem	Decline in NPP during land transformation	△	Transformation time is usually short.
		Decline in potential NPP during land use	○	NPP of each vegetation
		Decline in potential NPP during restoration period after land transformation	○	
	(Aquatic ecosystem)	Decline in primary production of phytoplankton	–	No consideration for use of water surface
Biodiversity	Terrestrial ecosystem	Change in composition of plant species	○	Extinction risk of vascular plants
		Change in composition of animal species	×	Quantitative impact assessment is difficult. Poor quantitative information
	(Aquatic ecosystem)	Change in composition of species in aquatic ecosystem	–	No consideration for use of water surface
Other	Global warming	Loss of CO_2 sinks, discharge of methane from soil, etc.	–	Secondary impact Classification into other categories
	Heat island	Decline in latent heat flux, increase in accumulated heat quantity	–	Secondary impact

a Calculation of damage factors according to category of land use

In the inventory of land use, the area of transformed land, the area of occupied land, and the period of occupation are grasped for each category of land use (see Column 2.10-2). This enables the classification system of types of land use to reflect differences in the land use classification system and available data among countries and regions.

A damage factor is given to each case of transformation or maintenance. In the case of transformation, a damage factor per unit area is presented for each combination (matrix) of types of land use before and after the transformation (however, with regard to the damage factor for biodiversity, the types of land use before the transformation are not taken into consideration). With regard to maintenance, a damage factor per unit area and per time is presented according to type of occupied land use.

b Approach to damage assessment and object of calculation of damage factors

Under LIME, for the purpose of damage assessment of land use, the assessment method by the endpoint approach was adopted as in the case of other impact categories. This method is classified into “(4) Indexing of biodiversity or the life maintaining function” in Table 2.10-1 for the purpose of impact assessment of land use.

The category endpoints of land use and the objects of calculation of damage functions under LIME are as shown in 2.10-3. With regard to the impact on the ecosystem, which is frequently recognized as an environmental problem as shown in 2.10.1 (2), some corresponding endpoint indices are included in the objects of calculation.

(2) Primary production: damage function for the terrestrial ecosystem

a Basic view on damage assessment

Because the primary production of plants is expressed by the volume of flow, the framework of damage assessment was created based on the following basic view under LIME. With regard to the maintenance of land use (land occupation), loss of NPP in the occupation period was calculated on the assumption that damage was no display of potential net primary production (NPP) (Figure 2.10-6). With regard to land transformation, loss of NPP was calculated in the period between the transformation of vegetation and the restoration of potential vegetation (Figure 2.10-7). This made it possible to add up the damage functions of transformation and maintenance.

b Formulation of damage assessment

Figure 2.10-8 (a) shows the definition of the amount of damage concerning the maintenance of land use. If land use “a” is occupied in a period between t_o and t_1, NPP of potential vegetation in a natural state (NPP_p) is suppressed by NPP of vegetation in the current state (land use) (NPP_a). The difference is regarded as lost NPP for the calculation.

In the case of damage assessment of maintenance, comparison with NPP_p is always made irrespective of type of land use before t_o. Based on this view, the definition was created as shown in the following equation on the assumption that the damage function per unit area and time in the case of maintenance of land use a $DF_{NPP}^{Occ}(a)$ [t ha^{-1} yr^{-1}] is the difference between the potential NPP (NPP_p [t ha^{-1} yr^{-1}]) and the current land use NPP (NPP_a [t ha^{-1} yr^{-1}]):

$$DF_{NPP}^{Occ}(a) = NPP_p - NPP_a \tag{2.10-1}$$

On the other hand, Figure 2.10-8 (b) shows the definition in the case of land transformation. If a category of land use “b” is transformed to another category “a” in the period between t_{-1} and t_0, what damage will be caused? If the period between t_{-1} and t_0 is sufficiently short, loss of NPP in the period is small (A in the figure). It can be usually thought that loss of NPP in a land transformation period can be ignored, compared with a maintenance period. In addition, if the category of land use “a” is maintained in the period between t_0 and t_1, the amount of damage becomes an object of assessment by land occupation in the above-mentioned (a). On the other hand, if the land use “a” is given up at the future time of t_1, restoration to the potential state “p” is delayed more than restoration from the land use “b” before the transformation. Therefore, primary production lost due to this delay was deemed to be the damage from transformation. Thinking in the same way, if giving up occupied land is delayed by one year, the amount of damage in the year is the same as the amount of damage in the above-mentioned year of occupation. The definition of the damage from transformation – loss by future delay in restoration – is well consistent with the definition of the damage from occupation.

As a concrete equation, the damage function per unit area due to transformation from land use "b" to "a", $DF_{NPP}^{Trans}(b,a)$ [t ha^{-1}] was defined as the following equation by the use of the time (restoration time) ($T_{b\to p}$, $T_{a\to p}$ [yr]) needed to restore land use b and a to potential natural vegetation if land use "b" (whose NPP is NPP_b) is transformed to land use a (whose NPP is NPP_a):

$$DF_{NPP}^{Trans}(b,a) = \alpha_{a\to p} \cdot (NPP_p - NPP_a) \cdot T_{a\to p} - \alpha_{b\to p} \cdot (NPP_p - NPP_b) \cdot T_{b\to p} \tag{2.10-2}$$

In this equation, *a* is fixed at 0.5 on the assumption that vegetation is restored linearly.

c Flow of calculation of damage function (by type of vegetation) and basic policy for uncertainty assessment

The spatial distributions of the NPP of potential natural vegetation (potential NPP) and the NPP of the current vegetation and land use (current NPP) in Japan were estimated in order to calculate damage functions. Figure 2.10-9 shows the flow of calculation (calculation procedure, the applied model, and data). Table 2.10-4 summarizes the causes of uncertainty considered for the assessment of uncertainty of damage functions and the way of treating them.

Details of each calculation process are described in "d" to "h" below.

Table 2.10-4: Main causes of uncertainty in the damage functions of land use to primary production and policies for treating them

Main possible causes of uncertainty		Policies for treating them in uncertainty assessment
Estimation of spatial distribution of potential NPP (2.10.3 (2) d)	Parameter of constitutive equation of Chikugo model	Estimated error in parameter of regression equation for estimation of proportionality coefficient α related to annual net amount of radiation *Rn*
		Estimated error in parameter of regression equation for estimation of monthly average water vapor pressure from temperature data
		Diversity of albedo on ground surface (assuming a uniform distribution of 0.5-0.8 when snowing and 0.05-0.25 when not snowing)
	Geographical variability	Calculation of frequency distribution of difference between current and potential NPPs in each mesh (in Japan and in each region)
Estimation of spatial distribution of current NPP (2.10.3 (2) e)	Representative value of NPP for each type of vegetation	Setting of unit production by normal distribution for each type of vegetation (Table 2.10-5)
Setting of restoration time of NPP (2.10.3 (2) f)	Transition time	Setting as uniform distribution by reference to various documents on assumption of secondary transition (Table 2.10-6)

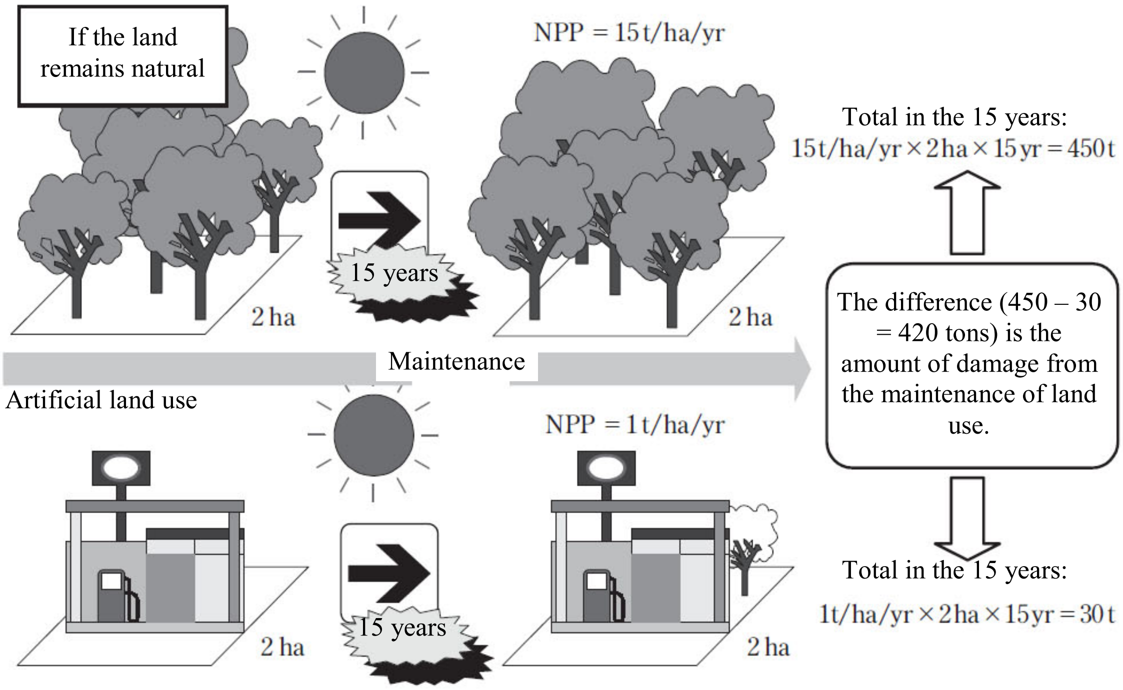


Figure 2.10-6: Image of the view on the calculation of the amount of primary production damage: maintenance of land use

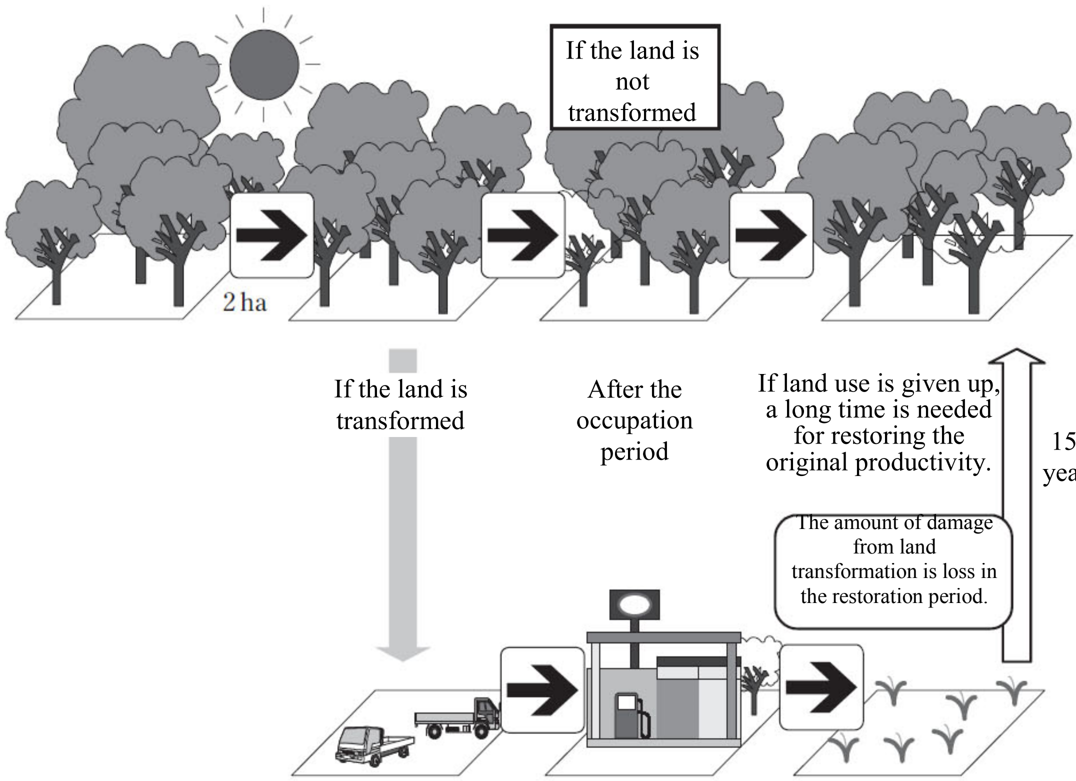
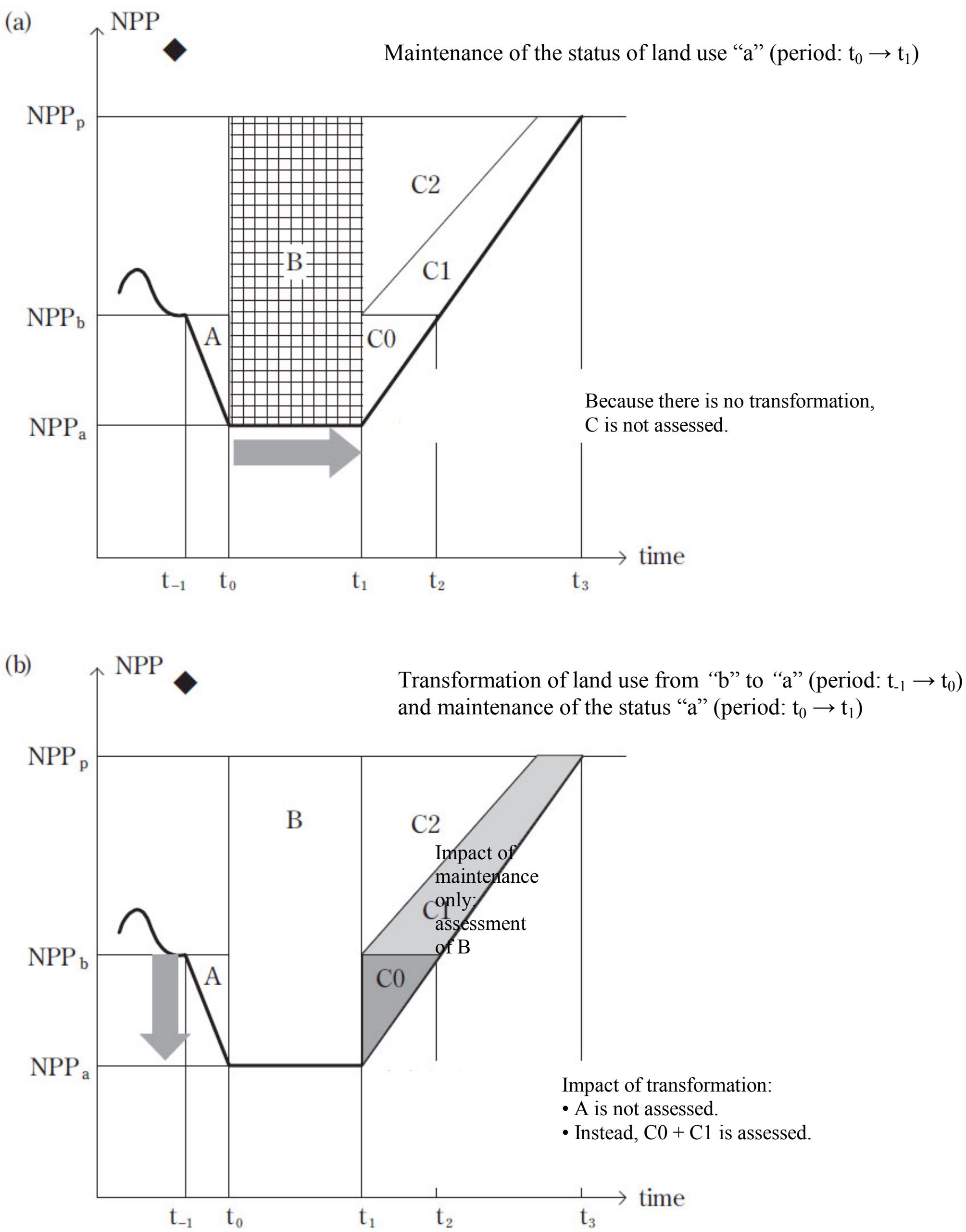


Figure 2.10-7: Image of the view on the calculation of primary production damage: land transformation



* Bold lines indicate changes in the status of land use subject to assessment.

t_{-1}: before land use transformation; t_0: after land use transformation; t_1: when land use is given up;
t_2: when NPP is restored to the level before transformation (NPP_b);
t_3: when NPP is restored the potential level (NPP_p)

Figure 2.10-8: Method to assess the amount of primary production damage

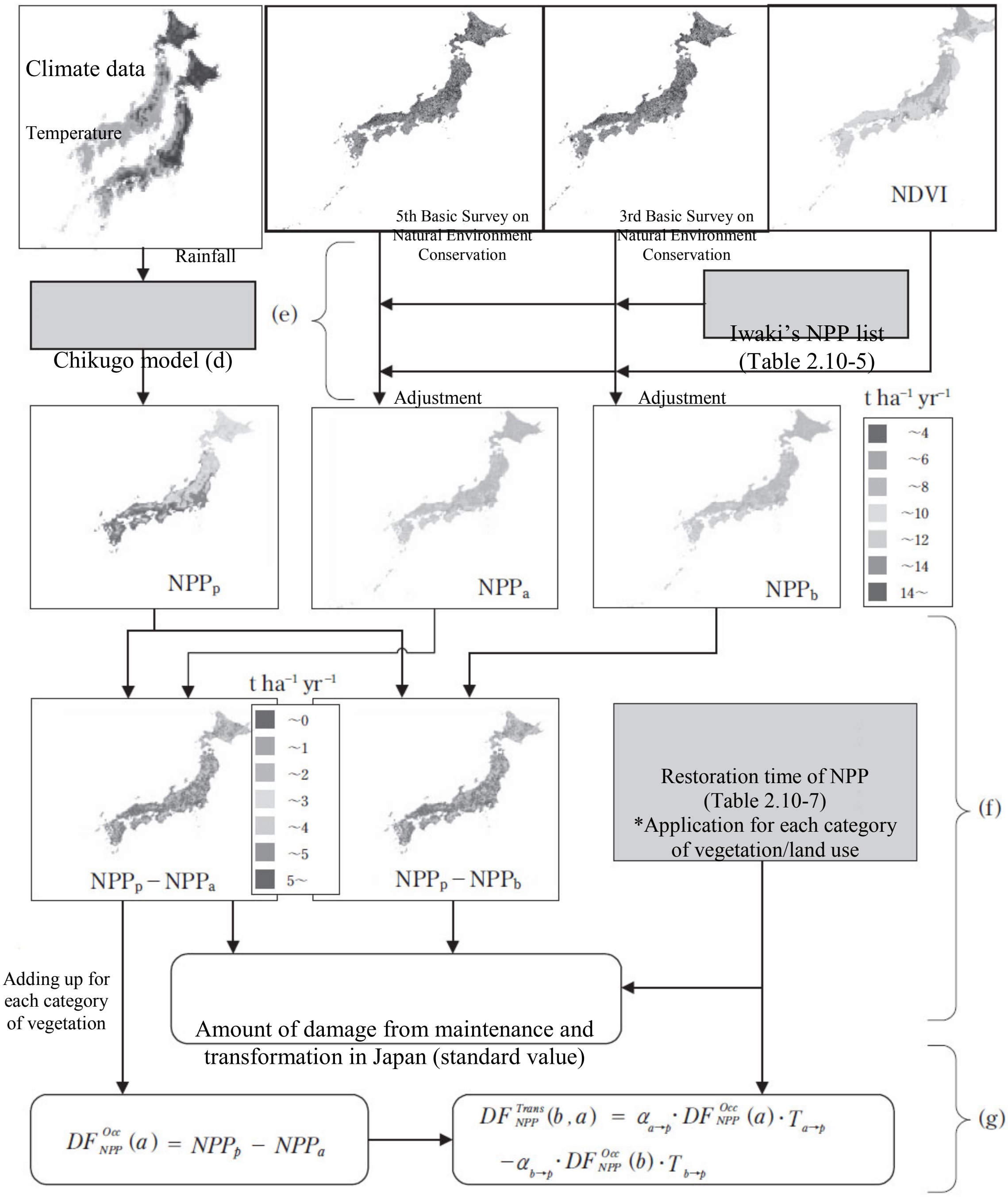


Figure 2.10-9: Flow of estimation of damage function of land use to primary production by type of vegetation

Shaded parts indicate factors for which uncertainty of parameter was taken into consideration.
Parts showing the Japanese Islands correspond to geographical changes.

d Estimation of spatial distribution of potential NPPs

When the spatial distribution of potential NPPs in the whole Japan were determined, two types of methods were examined: (1) numerical calculation by the Chikugo model (Uchijima 1985; Seino et al. 1985); and (2) the application of the unit production of vegetation (Iwaki 1981) corresponding to the legend of the potential natural vegetation map (Miyawaki et al. 1978). As a result, the former was adopted. Under LIME 2, the Japan Meteorological

Agency's observed normal values and the climate mesh data given by the National Institute for Agro-Environmental Sciences were used for the calculation by the Chikugo model as in Equation 2.10-3 (for details, see Column 2.10-4).

$$NPP = \alpha \cdot Rn = 0.29 \cdot \left[\exp\left(-0.216 \cdot RDI^2\right)\right] \cdot Rn \text{ [t ha}^{-1}\text{ yr}^{-1}\text{]} \qquad (2.10\text{-}3)$$

During the uncertainty assessment, of the parameters that constitute the Chikugo model, the following were considered: the estimated error in the parameter of the regression equation for estimation of the proportionality coefficient α related to the annual net amount of the radiation *Rn*, the estimated error in the parameter of the regression equation for estimation of the monthly average water vapor pressure from temperature data*[1], and diversity of albedo on the ground surface. With regard to the creation of the Chikugo model, it can be thought that because the proportionality coefficient is calculated by finding *Rn* through fixing of the value of albedo (when snowing and when not snowing) and having it regress to actually measured data of NPP, the proportionality coefficient itself changes if albedo changes. However, assessment was herein made with a uniform distribution of 0.5 to 0.8 when snowing and that of 0.05 to 0.25 when not snowing on the assumption that the two were separated from each other.

Table 2.10-5: Representative value of npp_i for each type of main vegetation and assumed standard deviation [t ha^{-1} yr^{-1}] by Iwaki (1981)

i	Category	NPP (I)	NPP (II) (adopted)		*i*	Category	NPP	
			Average	Standard deviation			Average	Standard deviation
1	Evergreen broadleaf forest	8	20	2.4	16	Deciduous orchard	10	1.3
2	Beech forest	6	9	1.2	17	Mulberry plantation	10	1.3
3	Birch forest	6	9	1.2	18	Dry field	12	1.5
4	Oak forest	6	9	1.2	19	Paddy field	11	1.4
5	Natural conifer forest	8	11	1.3	20	Fallow field	5	0.6
6	Pine forest	8	14	1.7	21	Bamboo grassland	8	1.0
7	Cedar/cypress forest	10	14	1.9	22	Rice plant field	8	1.0
8	Deciduous conifer forest	6	10	1.5	23	Amphibious grassland	15	1.9
9	Alpine shrub forest	5		0.6	24	Underwater grassland	1	0.1
10	Subtropical shrub forest	8		1.0	25	Special grassland	1	0.1
11	Low-mountain shrub forest	8		1.0	26	Large plants	15	1.9
12	Low-mountain deciduous forest	6		0.8	27	Small plants	1	0.1
13	Bamboo forest	10		1.3	28	Artificial grassland	8	1.0
14	Evergreen orchard	10		1.3	29	Urban green space	5	0.6
15	Tea plantation	7		0.9	30	Other	1	0.1

*[1] Under LIME 1, a regression equation by statistical processing of average values between 1951 and 1980 as shown in Seino et al. (1985) was used for setting the monthly average water vapor pressure and the snow index, and a regression equation by statistical processing of data between 1979 and 1982 as shown therein was used for setting the monthly average daily hours. Under LIME 2, a regression equation was formulated based on water vapor pressure and monthly average temperature data from meteorological observatories and stations all over Japan to estimate the parameter effort, using data between 1971 and 2000, the latest normal year data at the time of the research.

e Estimation of spatial distribution of current NPPs

The estimation of spatial distribution of current NPPs in the whole Japan was based on the method to give a current vegetation map that corresponds to each type of vegetation.

$$NPP = \sum_{i=1}^{n} npp_i \times A_i \tag{2.10-4}$$

In this equation, npp_i is the annual primary production per unit area in the type of vegetation i [t ha^{-1} yr^{-1}] and A_i is the area [ha] occupied by the type of vegetation i.

npp_i is the representative value of NPP for each type of main vegetation by Iwaki (1981) (Table 2.10-5). With regard to forest vegetation, Iwaki (1981) showed two types of NPP: NPP (I) for main types of adult trees only and NPP (II) that adds shrubs and grasses. We adopted the latter. In the uncertainty assessment, we checked the sources to which Iwaki (1981) referred to set values of NPP (Environment Agency 1976, Tadaki et al. 1968, Kira 1976), compared each of them with Table 2.10-5, and, with regard to the eight categories between evergreen broadleaf forest and deciduous conifer forest, supposed a normal distribution by the use of the latitude shown in Tadaki and Hachiya (1968) or Kira (1976) (on the assumption that the shown latitude corresponds to 3 σ). With regard to the classification of vegetation except for these eight categories, the average of the variation coefficients of the eight categories were given as the variation coefficient for each type.

A_i was calculated by the following procedure. The spatial distribution of the current vegetation was grasped from the natural environment information GIS data set based on the Environment Agency's Third and Fifth Basic Survey on Natural Environment Conservation. About 900 examples in the surveys were integrated into the 30 examples in Table 2.10-5. After that, 0.00125º-around mesh data (east-west: about 100 m; north-south: about 150 m) were prepared and, based on the data, A_i was calculated. When the standard amount of damage from transformation was calculated, NPP_b was used for the Third Basic Survey on Natural Environment Conservation (FY1983 - 87), while NPP_a was used for the fifth one (FY1993 - 1998).

Under this method, if the type of vegetation is the same, the value of the current NPP is the same everywhere in Japan. Actually, however, if the type of vegetation is the same, it is thought that the current NPP differs from place to place, depending on climate conditions. Therefore, we superposed the spatial distribution of normalized difference vegetation indices (NDVI) and multiplied the current NPP by a corrective coefficient, which can be calculated by dividing the average NDVI of all meshes for each type of vegetation by the NDVI of each mesh of the vegetation. NDVI is information that can be acquired from satellite image analysis (spectral reflection characteristics) and indexes differences in chlorophyll concentration and sunshine condition. Herein, we used data from "East Asia Monthly NDVI in 1997" (National Institute for Environmental Studies, Center for Global Environmental Research). The images are shown in Figure 2.10-9. Because introduction of adjustment by NDVI makes it possible to take into consideration the regionality of the current NPP, a reduction in the uncertainty of damage functions can be expected.

f Setting of restoration time

By reference to the time needed for transition of vegetation (secondary transition) (Hayashi 1990, Japan Institute of Energy 2002, Numata 1977), the time needed for each vegetation/land use to reach the level of primary production of a forest (restoration time) was set at the difference between the time of transition to a forest and the transition time of the vegetation. By reference to existing research, the restoration time was set at a value calculated on the supposition of secondary transition (Figure 2.10-9). In addition, thinking that restoration from land use that received strong artificial impact would took longer time, we set the restoration period at 150 years. Based on them, under LIME 2, we supposed the range of the transition time by the use of a uniform distribution as shown in Table 2.10-6.

Table 2.10-6: Transition time, equation for calculation of restoration time and application to type of vegetation

	Transition time (years) (supposed by uniform distribution)	Equation for calculation of restoration time [years] Figures in parentheses are restoration time established under LIME 1	Number of type of vegetation
Main tree period	15–45	0 (0)	1–8, 13
Shrub period	10–20	Transition time to main tree period－transition time to shrub period (15)	9–12
Main perennial grass period	2–15	Transition time to main tree period－transition time to main perennial grass period (20)	21–24, 26
Main annual grass period	0.5–1.5	Transition time to main tree period－transition time to main annual grass period (29)	25, 27
Artificial land use	0	Transition time to main tree period (30)	14–20, 28–30
Urban land use	–	50–250 (150)	30 (see Notes)

• The number of type of vegetation was based on Table 2.10-5, etc.
• The representative value of the restoration years from urban land use (applied to building sites and arterial traffic sites for damage functions of land use division) is five times as large as the transition time to the main tree period. The lower limit was set for the 20 years until the main grass period (by reference to Numata (1977)). The difference between the upper limit and the representative value was set at the same between the lower limit and the representative value.

Table 2.10-7: Process and results of calculation of damage functions corresponding to the classification of vegetation (example)

#	Type of vegetation	NPP_p	NPP_a	$DF_{NPP}^{Occ}(\#)$
1	Evergreen broadleaf	13	20	–6
2	Beech forest	12	9	3
3	Birch forest	10	9	1
4	Oak forest	12	9	3
5	Natural conifer forest	12	11	1
18	Dry field	12	12	1
19	Paddy field	13	11	3
20	Fallow field	14	5	9
21	Bamboo grassland	10	8	2
29	Urban green space	14	5	9
30	Other	14	1	13
31	Urban land use			

b# \ a#	1	2	29	30	31
1	0	0	129	194	972
2	0	0	129	194	972
3	0	0	129	194	972
4	0	0	129	194	972
5	0	0	129	194	972
18	-8	-8	121	186	963
19	-39	-39	89	155	932
20	-130	-130	-2	64	841
21	-23	-23	106	171	948
29	-129	-129	0	65	843
30	-194	-194	-65	0	777
31	-972	-972	-843	-777	0

- The left part shows damage functions of maintenance (unit: t ha^{-1} yr^{-1}) (#: number of type of vegetation), while the right part shows damage functions of transformation (unit: t ha^{-1}) (b#: vegetation number before transformation; a#: that after transformation).
- Whereas positive values indicate damage, negative ones indicate benefits.
- The damage function of maintenance is the difference between NPP_p calculated by the procedure specified in "d" and NPP_a calculated by the procedure specified in "e". The calculation of the damage factor of the "Other" type of vegetation only covered the types of land use "building sites" and "arterial traffic sites."
- The damage function of transformation was calculated from the damage function of maintenance and the recovery time calculated on the supposition of secondary transition (Table 2.10-6). With regard to the damage function of transformation related to the "Other" type of vegetation, this table shows both the result in the case of a restoration time of 30 years (#30) and the result in the case of types of land use that receive stronger artificial impact, such as building sites (#31).
- This is not the result of uncertainty assessment but an example that uses mesh averages, etc. to explain the calculation procedure.

g Calculation of damage functions corresponding to the classification of vegetation

We added up the results based on the spatial distribution of vegetation to find the damage function for primary production due to transformation and maintenance of each type of vegetation (Table 2.10-7). There are some differences in the estimated potential NPP (NPP_p) for each type of vegetation. For example, although the current NPP (NPP_a) of "bamboo grassland" is not so high, NPP_p of the region where bamboo grassland is distributed is relatively low as well. As a result, the amount of damage to maintenance of bamboo grassland has been assessed to be relatively small. On the other hand, while "idle farmland" is distributed in a region where NPP_p is relatively high, NPP_a was set at a relatively low value. Because of this, the amount of damage to maintenance has been assessed to be relatively large.

In addition, although NPP_a and NPP_p were set for each mesh, it can be thought that the two are related to each other if they are located in the same point of place. For example, according to the nationwide distribution map of NPP_a and NPP_p of cedar (Figure 2.10-10), there is a correlative relationship between NPP_a and NPP_p. Because of this, if the distribution of restoration time from NPP_a to NPP_p ($T_{a\rightarrow p}$) is supposed to be independent entirely during uncertainty assessment, the uncertainty of damage functions may be overestimated.

Under LIME 2, to prevent such overestimation of uncertainty, the geographical distribution of NPP_a and NPP_p was considered. Concretely, assessment was carried out by adding up the results of Monte Carlo calculation for each mesh and including the correlation of the geographical distribution among the elements of the damage function of maintenance. With regard to the damage function of transformation, because the fact that the point of place is the same before and after transformation was not taken into consideration, there are errors in the assessment results, and uncertainty may be overestimated.

h Calculation of damage functions according to the classification of land use for land use statistics

By the use of the results above, a damage function was introduced for each type of land use classified for land use statistics. Concretely, the spatial distribution of NPP_a and NPP_p and the land use dataset of the digital national land information (1/10 fine mesh data: 1987 - 1989)

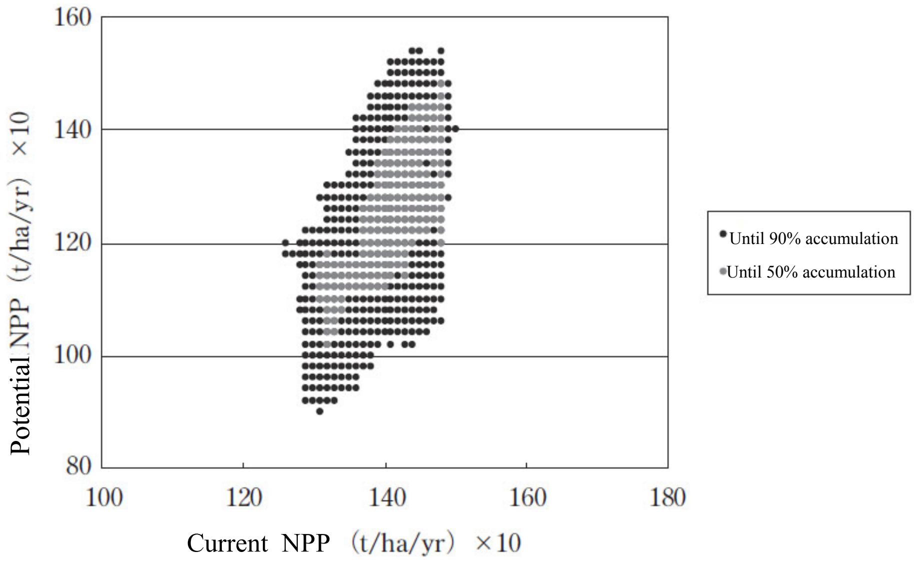


Figure 2.10-10: Example of (correlative) spatial distribution of current NPP and potential NPP (cedar)

Table 2.10-8: Process and result of calculation of damage functions corresponding to types of land use (example)

Maintenance			
Type of land use	NPP_p	NPP_a	Amount of damage
Paddy field	13	11	3
Dry field	12	10	1
Orchard	14	10	4
Other tree field	14	10	3
Forest	12	11	1
Wasteland	11	10	2
Building site	14	1	13
Arterial traffic site	14	1	13
Other site	14	6	8

Amount of damage from transformation		Types of land use after transformation				
		Paddy field	Dry field	Forest	Building site	Other site
Type of land use before	Paddy field	0	-20	-41	916	71
	Dry field	20	0	-21	937	91
	Orchard	-15	-35	-56	902	57
	Other tree field	-8	-28	-49	909	63
	Forest	41	21	0	958	113
	Wasteland	22	2	-19	939	94
	Building site	-916	-937	-958	0	-845
	Arterial traffic site	-908	-929	-950	8	-837
	Other site	-71	-91	-113	845	0

- The left part shows damage functions of maintenance (unit: t ha^{-1} yr^{-1}), while the right part shows damage functions of transformation (unit: t ha^{-1}).
- Whereas positive values indicate damage, negative ones indicate benefits.
- It is supposed that the types of vegetation corresponding to “building site” and “arterial traffic site” are always “other.”
- With regard to the damage function of the type of land use “forest,” the vegetation types #1 to #14 in Table 2.10-5 were covered by tabulation. The amount of damage also is not zero if “forest” is maintained. This is because the type of land use “forest” reflects the inclusion of vegetation for which NPP_a was set at a comparatively low value, such as shrubs. (For details, see 2.10.3 (4) a.)
- Because this is an example that uses the mesh average to explain the calculation procedure, it does not the same as the attached list of factors.

were superposed and added up. Although the precision of this calculation (Table 2.10-8) is lower than in the case of the classification of vegetation, it is easier for LCA users to use it, because the creation of an inventory is relatively easier.

When the damage factor was calculated for each type of vegetation (as described in the "g" above), although the ratio of type of vegetation to type of transition (the item "f") was fixed at *n* to 1, if the land use map is superposed on the vegetation map, various types of vegetation correspond to a certain type of land use. The restoration time for each type of land use under LIME 1 ($T_{b\to p}$, $T_{a\to p}$) was fixed at the average of the restoration times of the types of vegetation in all the meshes of a certain type of land use. Under LIME 2, based on the result of cross tabulation of both, the classification of land use statistics was made corresponding to the representative types of vegetation, and the transition time of the classification of land use statistics was deemed to be equal to the transition time of the representative types of vegetation. However, because the corresponding types of vegetation in forests and waste land were especially varied, the transition time was selected by using, as the probability distribution, the relative corresponding ratios of several types of vegetation that fall under "main tree period and shrub period" and "main perennial grass period, main annual grass period, artificial land use, and urban land use." With regard to "other sites" also, the restoration period for artificial land use was applied based on the result of tabulation of several corresponding types of vegetation in the same way.

The damage function of maintenance DF_{NPP}^{Occ} was used for $NPP_p - NPP_a$ and $NPP_p - NPP_b$.

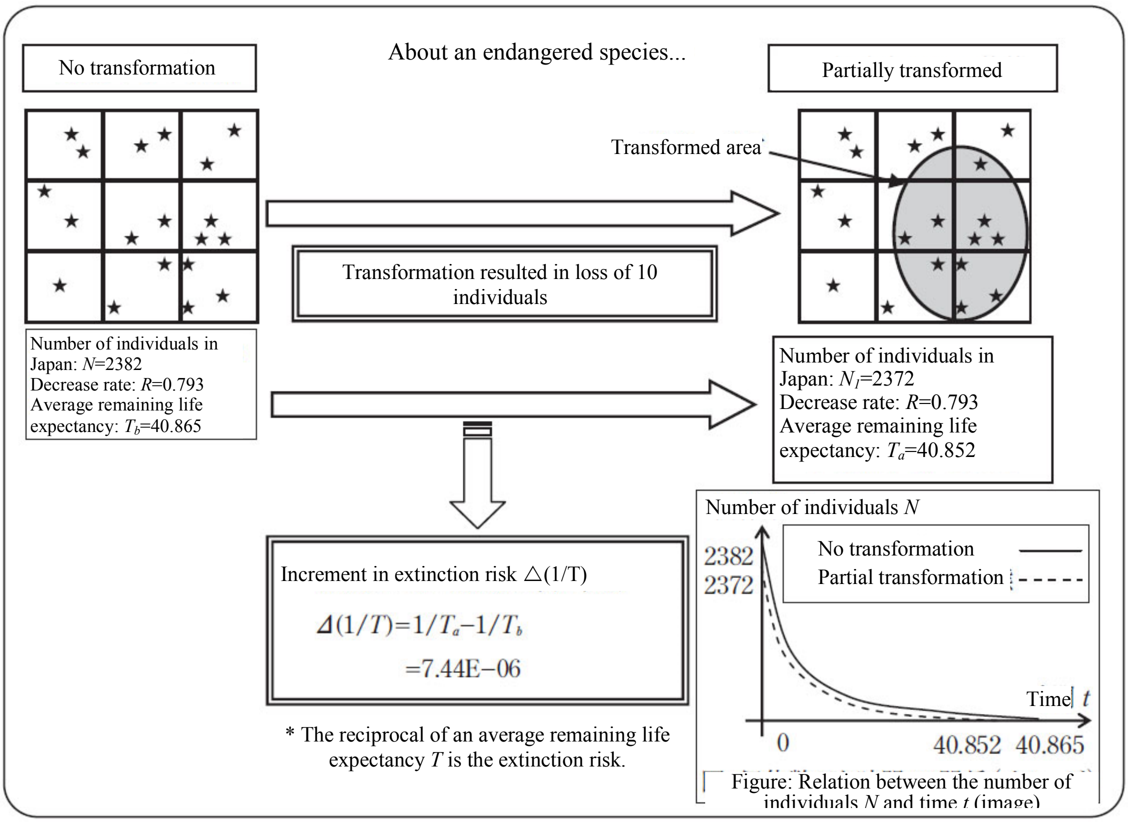


Figure 2.10-11: Calculation of an increase in the extinction risk (amount of damage) in a case of land transformation

Column 2.10-4

Methods to estimate the spatial distribution of NPP

There are various methods to estimate the spatial distribution of NPP.

The method to estimate NPP by the use of climate data (climatological estimation model) was suggested about 30 years ago. Among the study cases in Japan, the case where Kira (1976) used the warming index (WI) is well known. In addition to this, there were suggestions that the function of the annual average temperature, the annual rainfall, or the annual amount of vapor exhalation should be estimated. The MIAMI model by Lieth (1973) was representative.

On the other hand, Uchijima et al. (1985) took in a theoretical view on the processes related to primary production and suggested the Chikugo model as a model that takes into consideration various climatological parameters simultaneously.

Figure 2.10-C shows the flow of calculation of NPP by the use of the Chikugo model under LIME.

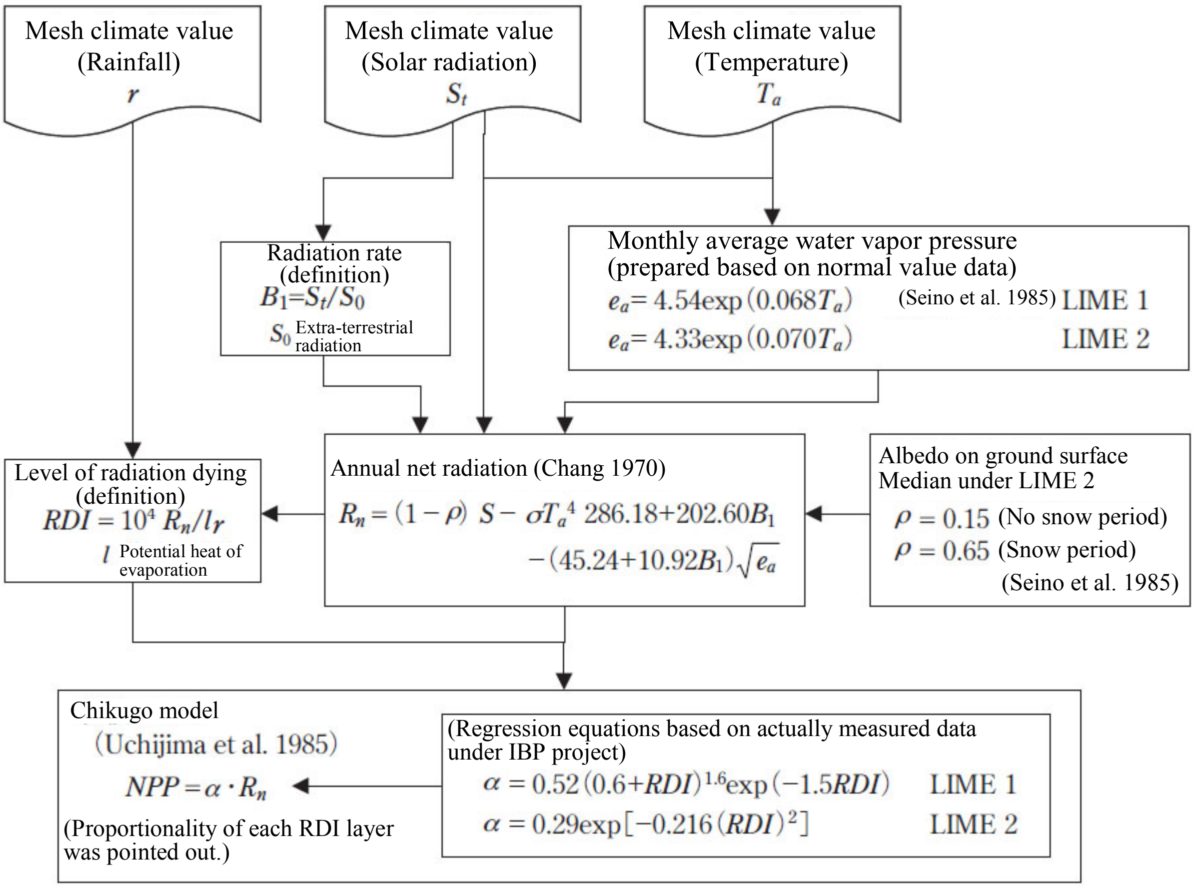


Figure 2.10-C: Flow of calculation of NPP by the use of the Chikugo model under LIME (Japan)

The Chikugo model estimates net primary production under a certain year's climate conditions from the net amount of radiation from the sun and the level of radiation drying that indicates the level of drying in the land (net amount of radiation/rainfall × potential heat of evaporation). Because of its characteristics, it is used also for assessing the impact of climate change on the physical production of plants. Moreover, because the model covers forests and other natural vegetation, it can be thought that the calculation result is production potential under a certain climate condition.

In addition, various estimation methods that use satellite data, whose availability has rapidly grown, have been suggested (Yamagata et al. 2002). One of the representative methods is the approach that estimates NPP by multiplying light use efficiency and the amount of photosynthetically active radiation. In this method, satellite data are directly used to find the amount of photosynthetically active radiation, for example.

Moreover, various models that incorporate biogeochemical processes have been developed (Cramer et al. 1999). Some of the indirect NPP estimation models even incorporate changes in vegetation, which makes estimation possible in a hypothetical situation.

Under LIME, to grasp the current NPP, the location situation of each type of vegetation was grasped based on the current vegetation map and was multiplied by the unit production volume of each type of vegetation fixed separately from actual measurement, etc. In addition, because the calculation result can be thought to be production potential under a certain climate condition, the Chikugo model was used for the estimation of the current NPP during the process of calculating the damage factors in the impact category of land use. Uchijima et al. (1985) shows two types of equations. Under LIME 2, Equation 2.10-3 was used for calculating the damage factors in Japan, because it is more suitable to Japan.

(3) Biodiversity: damage functions for terrestrial species

a Basic view on damage assessment

The damage function of the extinction risk due to land use indicates how much the extinction risk of species increases due to land use. Vascular plant species were selected for the assessment, because the diversity of plant species is more important than the diversity of the other species; unlike animals, plants cannot avoid the impact of land use by moving to other places; and available information is limited. The selection of vascular plant species for the assessment of the impact of land use on biodiversity is common throughout the world (see 2.10.2 (1)).

According to the red list of vascular plants that the Environment Agency published in 1997, “extinction probability” was used for judgment as to whether species were endangered ones or not (Column 2.10-5). Under LIME, damage functions were calculated based on the information written in the Red Data Book (RDB) (edited by the Environment Agency 2000), along with gathering and arranging a lot of information on local survey results about plant growth written in documents on environmental impact assessment (EIA) of large-scale projects accompanied by land transformation.

The assessment scope of the damage functions calculated under LIME is as follows: (1) only the direct impact of land transformation is dealt with, while the impact of maintenance of land use, such as loss of potential habitats, is not dealt with; and (2) the scope of assessment is limited to Japan in principle.

b　Formularization of damage assessment (flow of damage assessment in an transformation case)

What damage is caused by a change in type of land use from “b” to “a”? With regard to the impact propagation chart shown as Figure 2.10-1, attention is paid to the course through which some individuals of a plant species growing in a transformed area directly die unless special conservation measures are taken. This transformation will decrease the number of individuals of the plant species in the area or result in the extinction of the species as a whole. However, if some individuals are distributed widely in Japan and a group of a sufficient number of individuals is continuously maintained in each habitat, this kind of species will not become extinct for a while. On the other hand, if the number of habitats in Japan is very small, including the transformed area, if the species is distributed all over Japan, but each group consists of a small number of individuals, or if the number of individuals is sharply decreasing in any habitant, the transformation will increase the extension risk of the plant species without fail.

The damage assessment herein aims to find the degree of an increase in the extinction risk of vascular plant species in Japan due to a decrease in the number of individuals of species with a high extinction risk as described above – that is, endangered species. The assessment method is based on existing research carried out in liquefied natural gas (LNG) supply bases (Oka et al. 1999, Oka et al. 2001) and the planned site for Aichi Expo (Matsuda et al. 2003).

Under LIME, an increment in the extinction risk is expressed by difference in the reciprocal of the average extinction time of the species in question. This means that more importance is placed on the impact of species with shorter average life expectancy than indexing, such as finding difference in average extinction time (Matsuda 2000). Equation 2.10-5 shows the amount of damage from a transformation case (IER).

$$IER\,(b,a) = \Sigma_i \Delta(1/T)_i = \Sigma_i (1/T_{i,a} - 1/T_{i,b}) \qquad (2.10\text{-}5)$$

In this equation, T_i is the average extinction time of the species *i*. The attached *b* and *a* indicate the situation before and after the transformation, respectively. $\Delta(1/T)_i$ is an increment in the extinction risk of the species *i* due to a case of transformation in unit area from b to a. Totaling of $\Delta(1/T)i$ of all species means giving equal weight to each species. Under LIME, an increment in the extinction risk expressed by this index is deemed to be an expected increase in the number of extinct species and is abbreviated as EINES.

Figure 2.10-11 shows an image of calculation about an extinct species due to a transformation case. IER can be calculated by making such calculation about all the extinct species whose individuals are lost due to the transformation and adding up the results.

c　Flow of calculation of damage function and basic policy for uncertainty assessment

As shown in Figure 2.10-12, the damage function of the extinction risk due to land use was set at the representative value of the totals for each type of land use after finding IERs of several land transformation cases. In addition, Table 2.10-9 summarizes the uncertainty elements taken into consideration during the uncertainty assessment of the damage function and the way of treating them.

“d” to “h” below will describe the components of the calculation procedure and the process of the calculation.

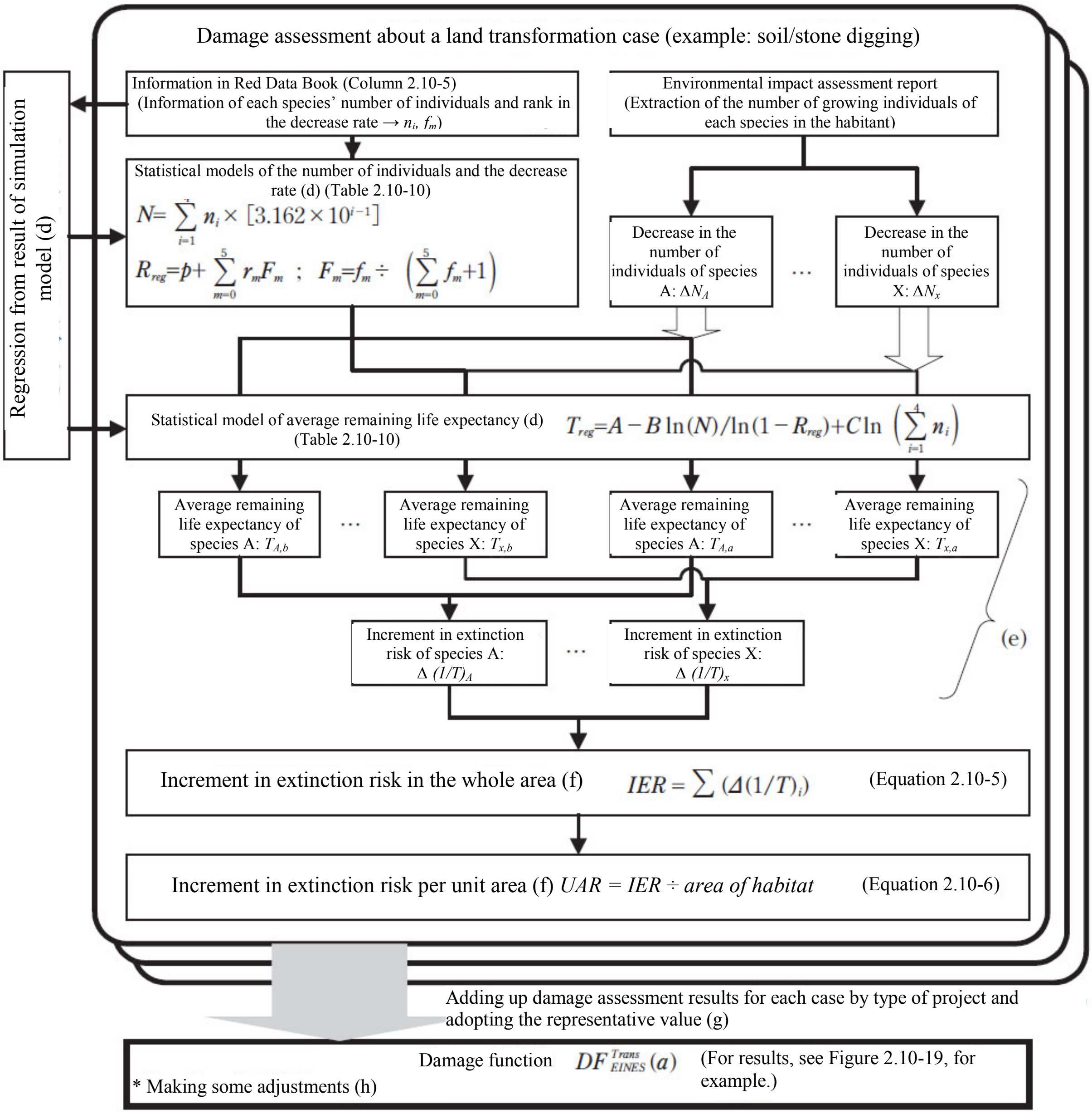


Figure 2.10-12: Flow of estimation of damage function of extinction risk due to land use

d Calculation model of average remaining life expectancy

Under LIME, the average life expectancy was calculated by a statistical model that estimates the number of individuals of endangered species in Japan N and the average decrease rate R from the number of meshes for the "number of existing individuals" of each of the endangered species written in RDB (edited by the Environment Agency, 2000) n_i and the number of meshes of the "decrease rate in the number individuals" of each of them f_m (see Column 2.10-5 and Table 2.10-A) and estimates of the average remaining life expectancy of the species T (Table 2.10-10).

This model was obtained based on Matsuda et al. (2003). The concrete procedure was as follows: first, R_{sim} and T_{sim} of 1,146 species were calculated by applying a simulation model by Matsuda (his website) (whose contents are similar to the simulation model used for the red list judgment explained in Column 2.10-5, but different in some points) after changes were made in some conditions, such as limiting the targets to the RDB-listed endangered species about which information necessary for calculation were obtained; next, regression analysis was carried out about the result and the representative values of parameters (regression factors) and standard errors were obtained for the equation for the calculation of R_{reg} and T_{reg} shown in Table 2.10-10. Under LIME 2, this estimated error was used for setting normal distribution (although, to be exact, this should have been *t* distribution, normal distribution was used because there were 1,146 species and latitude was wide). However, probability distribution was considered independent between parameters.

Table 2.10-9: Main causes of uncertainty in damage functions of the extinction risk of land use and policy for dealing with them

Main possible causes of uncertainty		Policy for dealing with them during uncertainty assessment
Average remaining life expectancy calculation model (2.10.3 (3) d)	Parameters of regression equation for average remaining life expectancy of species *T*	Estimated error in parameters of regression equation for decrease rate R_{reg} (Table 2.10-10) (7 parameters)
		Estimated error in parameters of regression equation for average remaining life expectancy of species *T* (Table 2.10-10) (3 parameters)
Calculation of increment in extension risk of each species in each environment assessment case (2.10.3 (3) e)	Probability distribution of average remaining life expectancy *T* (distribution of decrease rate in each mesh in RDB)	Applying probability density function for each evaluation target species to frequency distribution of average remaining life expectancy based on Monte Carlo simulation result T_{sim}, normalizing it by average value and multiplying T_{reg} by the result. (49 species)
	Number of individuals in Japan *N* (Indication by rank in RDB)	Regarding information on the number of individuals of each endangered species (example: Table 2.10-A), setting a number of growing individuals in each mesh in RDB according to rank in the number of them and adding up those in all the meshes where the number was reported (Table 2.10-10). Regarding *asarum satsumense*, however, probability distribution was established according to written description in RDB. (3,158 meshes/species)
	The confirmed number of individuals ΔN in cases subject to assessment (data form EIA materials)	If the confirmed number of individuals is expressed qualitatively in each piece of literature, a flexible value was set by uniform distribution, taking into consideration consistency with qualitative expression in context. (About 150 points/species)
Calculation of damage function by type of land use (2.10.3 (3) g)	Geographical variability Limitations in representativeness and the number of cases of land transformation subject to assessment	The amount of damage per unit area (UAR) in each assessment case by type of land use (type of project) was given as variability distribution by equal probability of occurrence (for estimation result of UAR for each case, see Figure 2.10-13). (37 cases)

Table 2.10-10: Equation for calculation of average life expectancy used in LIME (statistical model)

Estimation item	Equation (statistical model)	Equation parameter, etc. (Standard error in parenthesis)
Number of individuals in Japan (N)	$N=\sum_{i=1}^{4}\sum_{j=1}^{n_i}\log\text{–}N\left(\mu=N_i,\sigma=N_i\right)$ Herein log-N is lognormal distribution independent of i,j, $N_i=3.162\times10^{i-1}$.	n_i: number of meshes by "number of existing stumps", i=1: -10 stumps, i=2: -100 stumps, i=3: -1,000 stumps, i=4: 1,000 stumps-
Average decrease rate in decade (R)	$R_{reg}=p+\sum_{m=0}^{5}r_mF_m$ Herein, $F_m=f_m\div\left(\sum_{m=0}^{5}f_m+1\right)$	p=0.538 (0.001), r_0=0.464 (0.002), r_1=0.464 (0.004), r_2=0.411 (0.003), r_3=0.171 (0.002), r_4= -0.291 (0.002), r_5= -0.541 (0.002) f_m: number of meshes by "change from the past" m=0: extinction, m =1: -1/100, m =2: -1/10, m =3: -1/2, m =4: -1, m =5:1-
Average remaining life expectancy (T)	$T_{reg}=A-Bln(N)/ln\left(1-R_{reg}\right)+Cln\left(\sum_{i=1}^{4}n_i\right)$	A=1.891 (1.205), B=5.806 (0.067), C=7.572 (0.537)

Column 2.10-5

Judgment and extinction probability of endangered species in the Red List and the Red Data Book

The Red Data Book (RDB) summarizes the growth condition of endangered wild species and is used as a basic and important material for natural conservation.

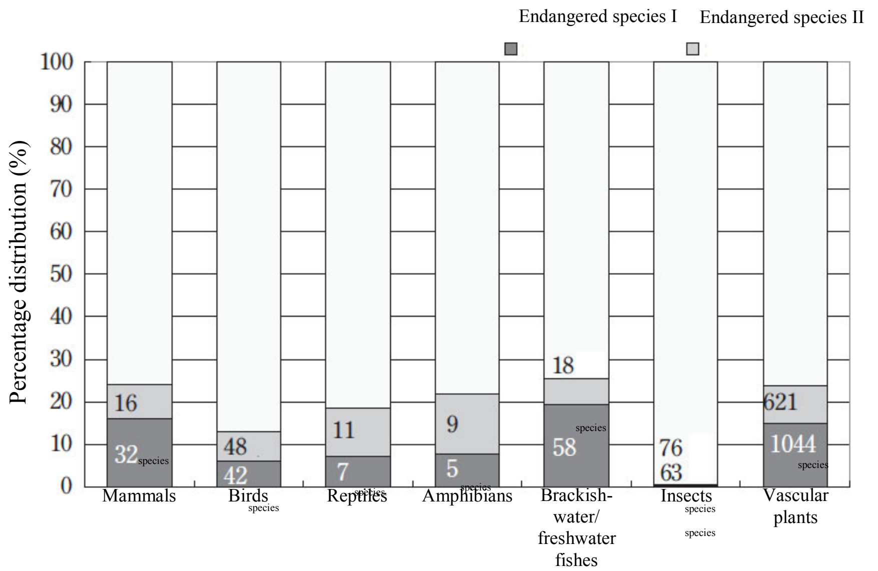


Figure 2.10-D: Ratio of endangered species to the total number of wild species in Japan by category

- Seven categories are shown in this graph among the 13 categories in the "Table of the Number of Species in the Red Data Book and the Red List" in the "2004 White Book on the Environment."
- Endangered species I consists of species on the verge of extinction, while endangered species II consists of species with an increasing extinction risk.

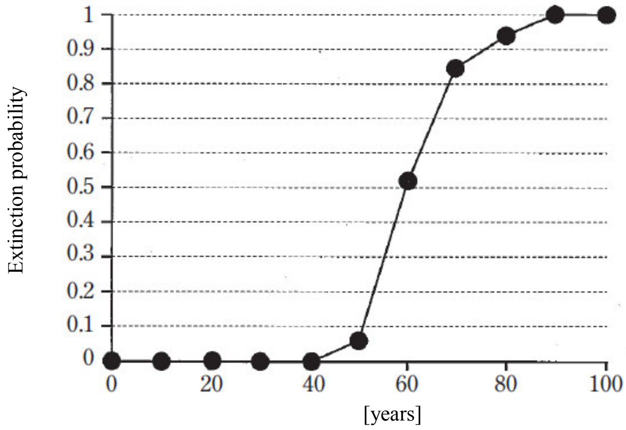


Figure 2.10-E: Example of calculation of cumulative extinction probability (primrose)

- The graph is reproduced from RDB of vascular plants (edited by Environment Agency 2000).
- Prepare meshes corresponding to the number of classes reported as existing concerning each type and set the number of individuals in each mesh according to class. In the case of Table 2.10-A, information is created for 17 meshes with 316 individuals according to "n_3: up to 1,000 stumps."
- A decrease rate is arbitrarily assigned to each mesh that holds a certain number of individuals, based on the data on the degree of decrease (the information on the number of meshes for each "change from the past" and supposition of hypothetical additional extinction meshes) (corresponding to a change in a decade).
- The result of implementation of this procedure for 100 years is regarded as the conclusion of one trial. Extinction occurs when the number of individuals in all the meshes becomes zero.

In Japan, the Ministry of the Environment began to review RDB in 1995. The review has been carried out at two levels: preparation and publication of a red list (list of endangered species to be included in RDB) about each category ("mammals," "vascular plants"); and editing of RDBs based on this one after another (the website of the Ministry of the Environment's Biodiversity Center of Japan).

In this assessment, judgment on endangered species was made by dividing the species subject to the assessment into some categories according to the scale of extinction risk. The International Union for Conservation of Nature and Natural Resources (IUCN), which edits RDB on a worldwide level, adopted new categories based on quantitative assessment standards in 1994 and reviewed the lists (IUCN's current categories and assessment standards are the 3.1 version created in 2001. A Japanese version translated by Yahara and Kaneko is made available to the public by the Japan Wildlife Research Center (http://www.jwrc.or.jp/).

A judgment method based on estimated extinction probability was adopted together with other quantitative and qualitative judgment methods for the judgment of endangered species of vascular plants in Japan. By the standards based on the extinction probability, for example, species whose extinction probability is estimated to be 10% or more 100 years after are judged to be endangered. This is said to be the first attempt in the world in which quantitative judgment of degree of risk was made about all the vascular plants in the Japanese islands.

Concretely, the assessment procedure was as follows: calculation of future changes in the number of individuals by computer simulation was tried a thousand times by the use of data on the number of individuals and the decrease rate in each target mesh (about 10-km square area) provided by naturalists and others (Table 2.10-A), and extinction probabilities 10, 20, and 100 years after were estimated based on the number of 1,000 trials resulting in extinction (Figure 2.10-E).

These data on the number of individuals and the decrease data in each mesh were derived based on accumulated survey data for several decades and the results of additional field surveys conducted during two years from FY1994. However, because it was impossible to research the habitats of all the target species in the two years, it is said that most of the estimated numbers of individuals may be underestimated.

As described herein, under LIME, the assessment index is Δ(1/*T*), which is a reduction in the reciprocal of *T*, the number of years until the extinction of each vascular plant species calculated based on data shown in RDB and others. If the number of existing individuals is underestimated, *T* also is underestimated and Δ*T* is overestimated due to loss of some individuals (see the equation for *T* in Table 2.10-10). Because of this, Δ(1/*T*) also is highly likely to be overestimated. However, this point is not reflected in the uncertainty evaluation under LIME 2.

Table 2.10-A: Example of information written in RDB (in the case of primrose)

Number of meshes by "number of existing individuals"						
n_1: up to10 individuals	n_2: up to100 individuals	n_3: up to1,000 individuals	n_4: 1,000 or more individuals	Unknown	Extinct	
12	60	17	6	13	23	
Number of meshes by "change from the past"						
f_1: up to1/100	f_2: up to 1/10	f_3: up to 1/2	f_4: up to 1	f_5:1 or more	Unknown	f_0: Extinct
8	25	24	10	6	45	13

Source: Revised Red Data Book: Endangered Wild Life in Japan – 8. Plants I (Vascular Plants) (Environment Agency 2000)

e Calculation of an increment in the extinction risk of each species in each environment assessment case

Under LIME, information on land transformation cases necessary for finding IER was obtained by gathering and arranging documents on environment impact assessment in the past (see 2.10.1 (1)), and an increment in the extinction risk was calculated for each species whose growth was confirmed in each case. With regard to the type and number of projects, under LIME 1, there were 30 projects in total: 16 projects for construction of roads in non-urban areas, 9 projects for digging soil and stone (area expansion), 4 projects for construction of final disposal facilities, and 1 project for railway construction. Under LIME 2, information about 2 road construction projects, 2 projects for digging soil and stone, and 3 projects for construction of final disposal facilities was researched and added.

First, arrangement was made about the status of confirmation of RDB-listed species, the scope of research, and the scopes of the projects during a field survey on flora written in each environment impact assessment document (hereinafter, the RDB-listed species confirmed locally was called the "target species"). With regard to projects before the issuance of RDB, whether they were listed in RDB was checked only about the species listed as "valuable vascular plants" in each project. If a species was listed, it was included in the target species. Next, with regard to each target species, based on data written in RDB and by the use of the above-described statistical model (Table 2.10-10), the average life expectancy T_b was calculated from *N*, the number of individuals in Japan calculated from information written in RDB, and T_a, the average remaining life expectancy if the number of individuals in the target area for each project (ΔN) disappear (N–ΔN) in each project was calculated. Then, for each target species, a difference in average remaining life expectancy, $\Delta T = T_b - T_a$, and an increment in the extinction risk (an increment in the reciprocal of average remaining life expectancy), $\Delta(1/T) = 1/T_a - 1/T_b$, and log $\Delta(1/T)$ were calculated. Among them, $\Delta(1/T)$ is used as the damage index under LIME as described above.

There were differences in the degree of details of description about endangered species (especially, the expression of the number of confirmed species) and the existence in conservation measures. Because of this, under LIME, when basic information for the calculation of an increment in the extinction risk was arranged, including setting a range (concept) of assessment targets, the extinction risk was calculated after the establishment of a uniform survey policy. As a result, it is appropriate to interpret the increment in the extinction risk calculated under LIME not as direct evaluation of the impact of a decrease in the number of individuals caused actually by the implementation of each development project, but as the size of the potential impact that reflects a location situation where such a project can be planned.

Under LIME 2, the probability distribution of average remaining life expectancy T, the estimation of the number of individuals in Japan N based on RDB (also see Column 2.10-5), and the number of confirmed individuals not expressed by specific values in environmental impact assessment literature were included in the uncertainty assessment. Table 2.10-9 shows details of the setting.

f Calculation of the amount of damage (IER and UAR) in each case

An increment in the extinction risk (IER) in this case was calculated by adding up the increments in the extinction risk of the species in each of the above-mentioned environmental impact assessment cases (Equation 2.10-5). Next, an increment in the extinction risk per unit area (UAR) in each case was calculated by dividing IER by A, the area of the extent of the extinction risk assessment (research extent, etc.).

$$UAR = IER \div A \qquad (2.10\text{-}6)$$

Table 2.10-11 shows an example of calculation of IER and UAR.

Table 2.10-11: Example calculation of the amount of damage (increment in the extinction risk)

Confirmed RDB species		Before transformation			No. of confirmed individuals in the project area	After transformation		Increment in the extinction risk		
Class	Item	No. of individuals	Decrease rate	Average remaining life expectancy		No. of individuals	Average remaining life expectancy	△T	△(1/*T*)	log△(1/*T*)
Vittaria flexuosa	*Antrophyum obovatum*	230	0.856	43.934	1	229	43.920849	0.013	6.73E-06	-5.17
Scrophulariaceae	*Siphonostegia laeta*	1396	0.310	143.553	9	1387	143.45173	0.101	4.92E-06	-5.31
Orchid	*Cephalanthera falcate*	2801	0.583	93.289	1	2800	93.286452	0.002	2.73E-07	-6.56
						Total		0.117	1.20E-05	

$IER = \Sigma\Delta(1/T)$=1.20E-5 [EINES], $UAR = IER \div$area (280ha) =4.27E-8 [EINES ha^{-1}]

g Calculation of damage function by type of land use

The increment in the extinction risk per unit area calculated for each case and the target area were arranged for each type of project as shown in Figure 2.10-13. As a result, because the value greatly differed among cases, under LIME 1 it was judged appropriate to show the representative value as an approximate number based on the median. Under LIME 2, the median serves as the representative value in the impact categories where uncertainty assessment was carried out, and the same applies to this damage function.

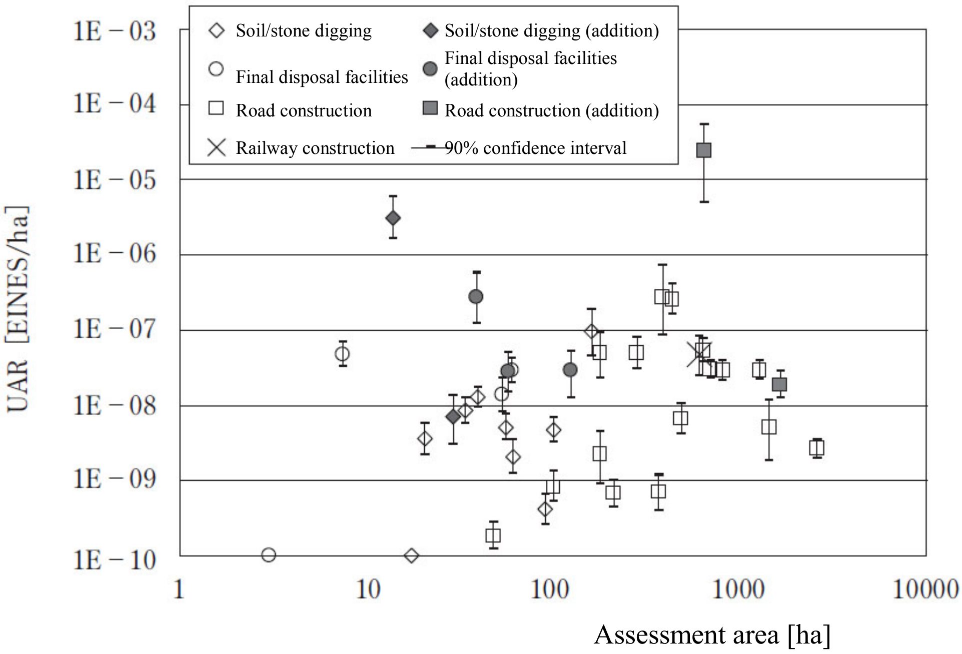


Figure 2.10-13: Result of calculation of the amount of damage per unit area (UAR) in each case

- The graph shows the average (marker) and the 90% confidence interval obtained as a result of uncertainty assessment of UAR (IER ÷ assessment area) in each case. For an outline of uncertainty assessment of IER, see Column 2.10-5 and Table 2.10-9.
- Because UAR is 0 in the case of the digging zone expansion project and the final disposal facilities construction project (one project each), about which a species subject to extinction risk assessment in this study were not reported in environmental impact assessment literature, this graph shows it as IE-10 for convenience sake.
- The "addition" in the legend means a case of environmental impact assessment where UAR was calculated by gathering and arranging new information under LIME 2.

Moreover, under LIME 2, on the assumption that land transformation shown in the inventory could not be identified when it is made "somewhere" in Japan, spatial variability was added to the uncertainty assessment also in this impact category. Concretely, a set of UARs obtained this time was given as equiprobability distribution. Therefore, the obtained result has a wider probability density distribution than the estimated error in the median (representative value) as described below.

The obtained damage function has the following characteristics: (1) regarding road construction, the situation of check of endangered species widely differs among cases, and the extinction risk per unit area differs greatly; (2) regarding the target cases, the potential impact per unit area of the final disposal facilities construction projects was larger than that of the soil and stone digging zone expansion projects; (3) regarding the soil and stone digging zone expansion projects and the final disposal facilities construction projects, it was thought possible to carry out impact assessment in relation to resource consumption and waste disposal, other impact categories ; and (4) regarding road construction projects, it was thought that more examination would be necessary when applying to LCA.

h Adjustment of damage function by standard value

Based on values written in RDB, the yearly decreasing number of individuals of each endangered species was estimated by multiplying by the estimated number of individuals in Japan. When the average remaining life expectancy before and after the decrease was calculated only for the yearly decreasing number of individuals and the total increment in the extinction risk of all the target endangered species was calculated by Equation 2.10-5, the total increment was 0.553. The annual amount of damage due to land transformation was 0.198 if the result was simply divided by the ratio of answered meshes of decrease causes (excluding deforestation) related to land use (transformation) reported in RDB (Figure 2.10-2).

On the other hand, if the amount of damage per unit area in the above-mentioned road construction cases is multiplied by the annual road construction area and is divided by the ratio of answered meshes of decrease cases (ratio of road construction to all the cases related to land transformation) to find the amount equivalent to annual damage due to causes related to land transformation, the result was 0.00120, which is extremely different from the above result.

As a result of examination of the cause, among the plant species observed in the environmental impact assessment cases, the number of those belonging to the endangered species IA (CR), whose extinction risk is higher than the other endangered species, was small, while the number of those belonging to the endangered species IB (EN) and especially the endangered species II (VU) is large. Moreover, an increment in the extinction risk per decrease of an individual was small concerning most of the UV species. This was thought to be a cause of the great difference between the two (Figure 2.10-14) (As a characteristic of the index $\Delta(1/T)$, which was selected as the damage index that indicates the extinction risk, as shown above, the impact on species whose average remaining life expectancy is low, such as the CR species, is regarded to be relatively high).

As a result of examination of geographical bias of the cases and examination of differences caused by the non-linear nature of the increment in the extinction risk due to a decreasing number of individuals (the equation for calculation of average remaining life expectancy (Table 2.10-10) is non-linear in terms of the number of individuals. On the other hand, when the decreasing number of individuals is small in each land transformation case, compared with the yearly decreasing number of individuals in Japan), their impact was thought to be not conspicuous.

In the inventory in usual LCA cases, details of land transformation are thought to be unknown. Given the standard value based on the nationwide number of individuals grasped in RDB, the damage function based only on the environmental impact assessment cases gathered this time may lead to underestimation of the extinction risk. Therefore, the value adjusted through multiplication by 164, the ratio between the two, was finally adopted as the damage function. If the status of growth of endangered species in the transformed land, it is possible to make assessment without applying the adjustment coefficient, by directly calculating the UAR of the land by the above-described calculation method.

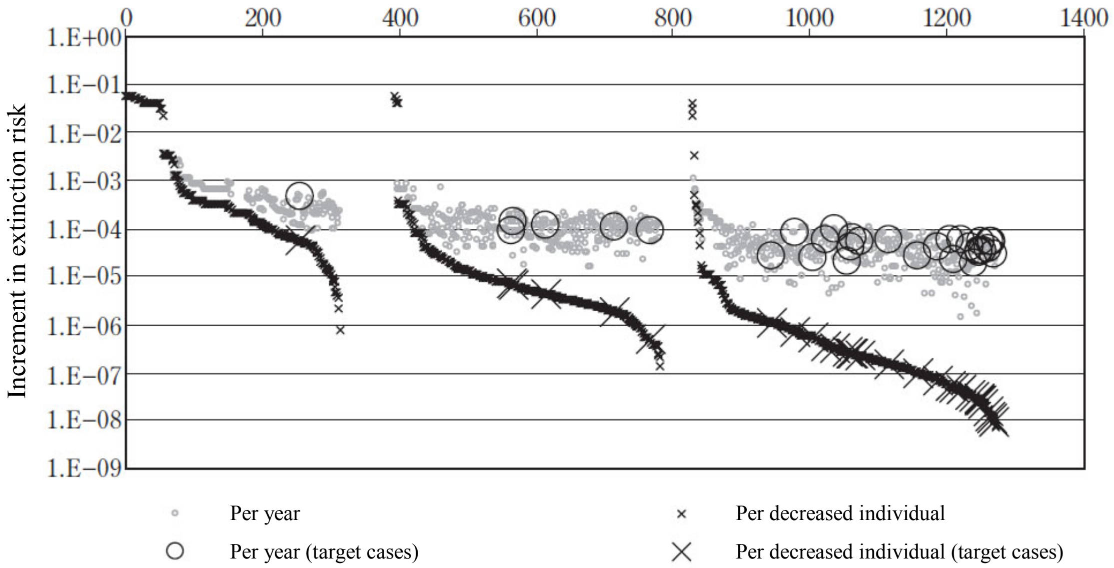


Figure 2.10-14: Relation between all RDB-listed species whose average remaining life expectancy can be calculated and the species confirmed in the target cases (EIA)

In the cases (EIA) covered by LIME 1, the graph shows that, mainly, species whose increment in the extinction risk is relatively small at the time of decrease of an individual has been confirmed. Because of this, if the result of calculation only based on the cases subject to the assessment this time is used as is, underestimation may occur in the application to LCIA.

Column 2.10-6

Promotion of LCA with consideration for regionality – damage function in accordance with the location of land use

The impact of land use on the ecosystem greatly differs from region to region. Therefore, it is favorable to carry out assessment that reflects not only the classification of land use but also the location of the land, vegetation, and other detailed conditions. However, it would be difficult to apply this to LCA.

However, if inventory makes it possible to grasp information on the geographical location of land use, it may be possible to carry out more detailed impact assessment.

Under LIME, the damage function due to the extinction risk was calculated for each mesh (each coordinate) by arranging the distribution of the RDB-listed endangered vascular plant species about which distribution information is open to the public, using data on them (provided by the Ministry of the Environment's Biodiversity Center of Japan), and comparing the distribution with each impact assessment case. For details, see Abe et al. (2003). If more accurate assessment is needed, it is necessary to carry out a (field) survey on the number of individuals of endangered species. However, this is beyond the scope of current general LCA; it is within the territory of the environmental assessment (EIA) of each project.

Table 2.10-12: Damage factor for primary production due to land use (maintenance) (extraction of some types of land use) ($DF_{NPP}^{LandUse(Dcc)}(a)$ unit: kgDW m^{-2} yr^{-1})

Type of land use (a)	Paddy field	Dry field	Forest	Building site	Other site
No. of trials	500	500	500	500	500
Average	2.74E-01	1.40E-01	1.04E-01	1.28E+00	7.54E-01
Median	2.55E-01	1.35E-01	1.15E-01	1.28E+00	7.35E-01
Standard deviation	2.96E-01	3.10E-01	3.39E-01	2.17E-01	5.21E-01
Dispersion	8.75E-02	9.62E-02	1.15E-01	4.71E-02	2.71E-01
Skewness	0.37	0.37	-0.09	0.08	-0.11
Kurtosis	3.60	3.62	2.81	2.80	2.00
Variation coefficient	1.08	2.22	3.26	0.17	0.69
10% value	-8.50E-02	-2.55E-01	-3.55E-01	1.01E+00	6.50E-02
90% value	6.55E-01	5.25E-01	5.35E-01	1.57E+00	1.43E+00

• Positive values indicate damage, whereas negative values indicate benefits.

Table 2.10-13: Damage factor for primary production due to land use (transformation) (extraction of some types of land use) ($DF_{NPP}^{LandUse(Trans)}(b,a)$ (unit: kgDW m^{-2})

Type of land use before transformation (b)	Paddy field	Paddy field	Dry field	Forest	Wasteland
Type of land use after transformation (a)	Forest	Building site	Other site	Building site	Arterial traffic site
No. of trials	50000	50000	50000	50000	50000
Average	-4.05E+00	9.17E+01	9.13E+00	9.57E+01	9.26E+01
Median	-3.54E+00	8.88E+01	8.41E+00	9.28E+01	8.96E+01
Standard deviation	4.85E+00	4.11E+01	1.00E+01	4.08E+01	4.07E+01
Dispersion	2.35E+01	1.69E+03	1.01E+02	1.67E+03	1.66E+03
Skewness	-0.68	0.33	0.20	0.34	0.32
Kurtosis	4.62	2.37	2.86	2.35	2.34
Variation coefficient	-1.20	0.45	1.10	0.43	0.44
10% value	-1.02E+01	3.90E+01	-3.08E+00	4.32E+01	4.07E+01
90% value	1.40E+00	1.48E+02	2.28E+01	1.52E+02	1.49E+02

• If the type of land use is in reverse order, apply $DF_{NPP}^{LandUse(Trans)}(b,a) = -DF_{NPP}^{LandUse(Trans)}(a,b)$.

• Positive values indicate damage, whereas negative values indicate benefits.

(4) Damage factor of land use

Because, in the impact category of land use, the number of types of damage factor for primary production or the extinction risk is one, the representative value of the damage function serves as the damage factor as is.

a Damage factor for primary production

With regard to the damage factor for primary production, Tables 2.10-12 and 2.10-13 show statistical values, Figures 2.10-15 and 2.10-16 show probability density distributions and Table 2.10-14 shows rank correlation. In addition, Figures 2.10-17 and 2.10-18 show comparison with LIME 1.

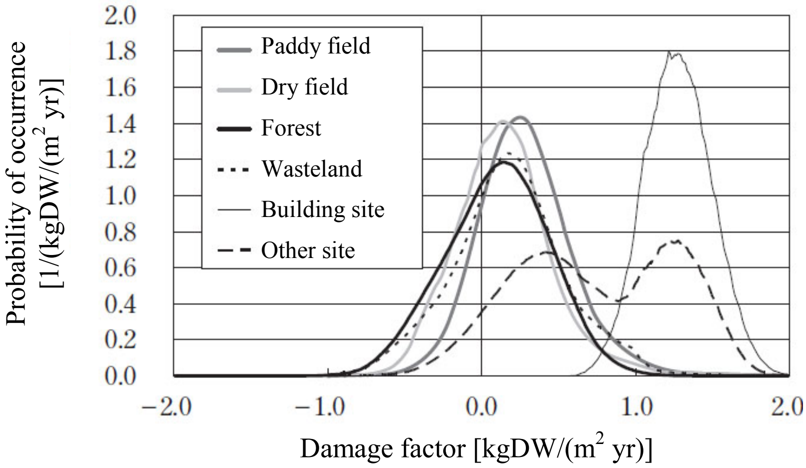


Figure 2.10-15: Damage factor for primary production due to land use (maintenance) (extract of some types of land use) ($DF_{NPP}^{LandUse(Dcc)}(a)$)

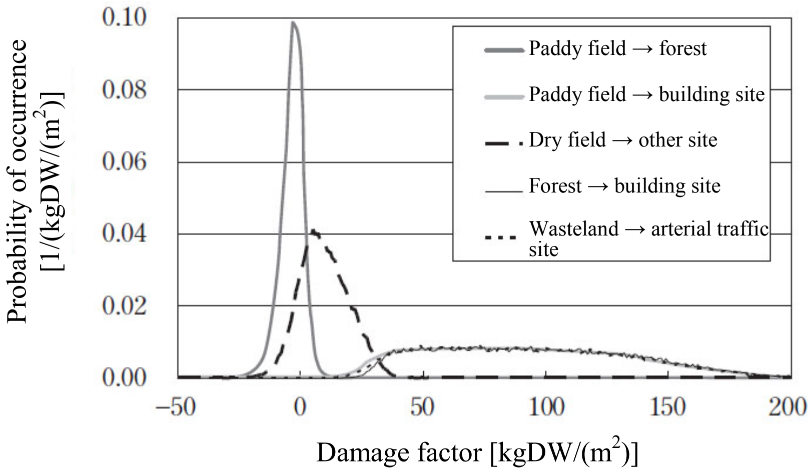


Figure 2.10-16: Damage factor for primary production due to land use (transformation) (extract of some types of land use) ($DF_{NPP}^{LandUse(Trans)}(b,a)$)

According to Table 2.10-12, the median of the damage factor is positive in any type of land use. Because of this, if this assessment factor is used, even when a forest is conserved, it is judged that the forest has damage. Unlike in the case of many other impact categories and objects of protection, but like the confidence intervals shown in Figure 2.10-17 that uses not logarithmic but arithmetic scale, the standard deviation of the damage factor is almost at the same level, except for some intervals. Because of this, the smaller the average (≒ median) of the damage factor, the larger the variation coefficient tends to become. Especially with regard to the types of land use, because there are various types of forests, they include the types of vegetation regarded as having small NPP, such as various types of shrubs listed in Table 2.10-5. Because there are many cases (meshes) where the damage factor is judged to be positive, as a result, the probability density distribution of damage factors is bilaterally symmetric, centering almost on 0, as shown in Figure 2.10-15.

With regard to the damage functions in the other impact categories under LIME, the amount of damage is calculated by "multiplication," while the amount of damage from the maintenance of land use is calculated by "subtraction" from the referential state as shown in the equation for definition (Equation 2.10-1). Because of this, it is better to understand that the difference between the two is about 1 kgDW/(m^2 yr) rather than understanding that the damage factor for a building site is about 10 times that of a forest. Therefore, attention should be paid to the interpretation of the result. It would be effective to grasp this quantitatively by carrying out uncertainty assessment under LCA by the use of the probability density distribution information on damage factors shown in LIME 2.

Table 2.10-14: Example of rank correlation coefficient of damage factor for primary production due to land use (transformation)

b	Paddy field		Dry field		Forest	
a	Forest		Other site		Building site	
#1	$DF_{NPP}^{LandUse(Occ)}(b)$ $b=$ Paddy field	−0.94	$DF_{NPP}^{LandUse(Occ)}(a)$ $a=$ Other site	0.79	Restoration time for primary production ($T_{a\to p}$)	0.92
#2	Restoration time for primary production ($T_{p\to p}$)	−0.23	$DF_{NPP}^{LandUse(Occ)}(b)$ $b=$ Paddy field	−0.44	$DF_{NPP}^{LandUse(Occ)}(a)$ $a=$ Building site	0.36
#3	$DF_{NPP}^{LandUse(Occ)}(a)$ $a=$ Forest	0.04	Restoration time for primary production ($T_{a\to p}$)	0.31		
#4			Restoration time for primary production ($T_{b\to p}$)	−0.05		

- b: type of land use before transformation; a: type of land use after transformation
- Variables with a rank correlation coefficient of 0.05 or more were extracted.

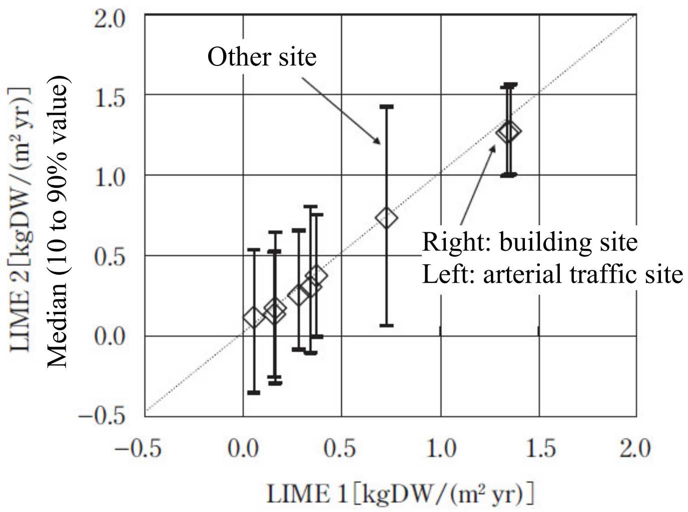


Figure 2.10-17: Comparison of LIME 1 and LIME 2 in the damage factor for primary production due to land use (maintenance)

- Because various types of vegetation (NPP_a) correspond to the type of land use "other site," the confidence interval has become wider. (See Figure 2.10-15.)
- Because, under LIME 2, NPP_a for "building site" and "arterial traffic site" is not regarded as 0, but NPP_a of the type of vegetation "other" is used, the result becomes smaller than that of LIME 1 by 0.1 kgDW / (m^2 yr).

b Damage factor for biodiversity

With regard to the damage factor for an increment in the extinction risk, Table 2.10-15 shows the statistical amount and Figure 2.10-19 shows the cumulative probability density distribution. Like LIME 1, the target cases show that the potential impact of the final disposal facilities construction projects may well be higher than that of the soil and stone digging zone expansion projects.

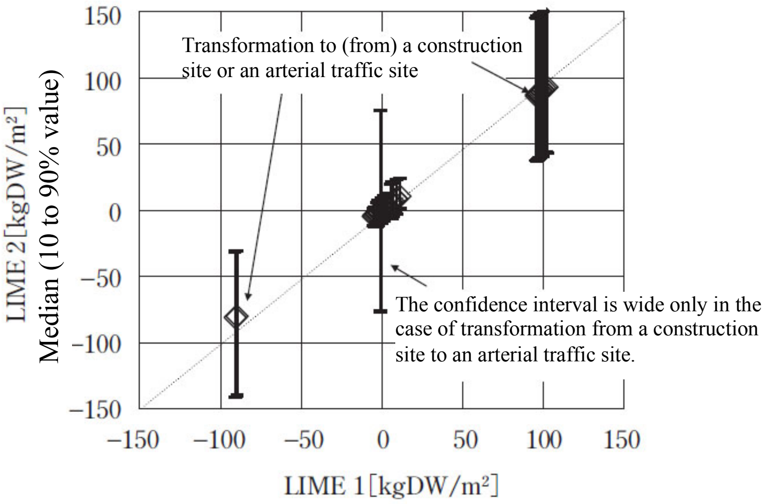


Figure 2.10-18: Comparison of LIME 1 and LIME 2 in the primary production damage factor due to land use (transformation)

Table 2.10-15: Damage factors for the extinction risk due to land use ($DF_{EINES}^{Trans}(a)$)

(Unit: EINES/m^2)

Type of project (a)	Road construction (Non-urban district)	Soil/stone digging	Construction of final disposal facilities	Other (Default)
No. of trials	50,000	50,000	50,000	50,000
Average	2.77E-08	4.86E-09	9.97E-10	1.07E-08
Median	3.49E-10	8.28E-11	4.44E-10	2.22E-10
Standard deviation	8.48E-07	1.62E-08	1.77E-09	1.22E-07
Dispersion	7.19E-13	2.63E-16	3.14E-18	1.49E-14
Skewness	125.4	4.1	3.7	59.6
Kurtosis	19050.3	22.0	20.9	5,187.9
Variation coefficient	30.6	3.3	1.8	11.5
10% value	9.07E-12	4.24E-12	0.00E+00	6.60E-12
90% value	4.17E-09	2.65E-09	3.01E-09	3.46E-09
Average standard error	3.79E-09	7.25E-11	7.92E-12	5.46E-10

- Regarding $DF_{EINES}^{Trans}(b,a)$, damage factors have been put together into those related to *b*, the land use before transformation.
- Under LIME 2, a variability distribution of UARs in all the cases subject to the assessment is used for the other types of land use.

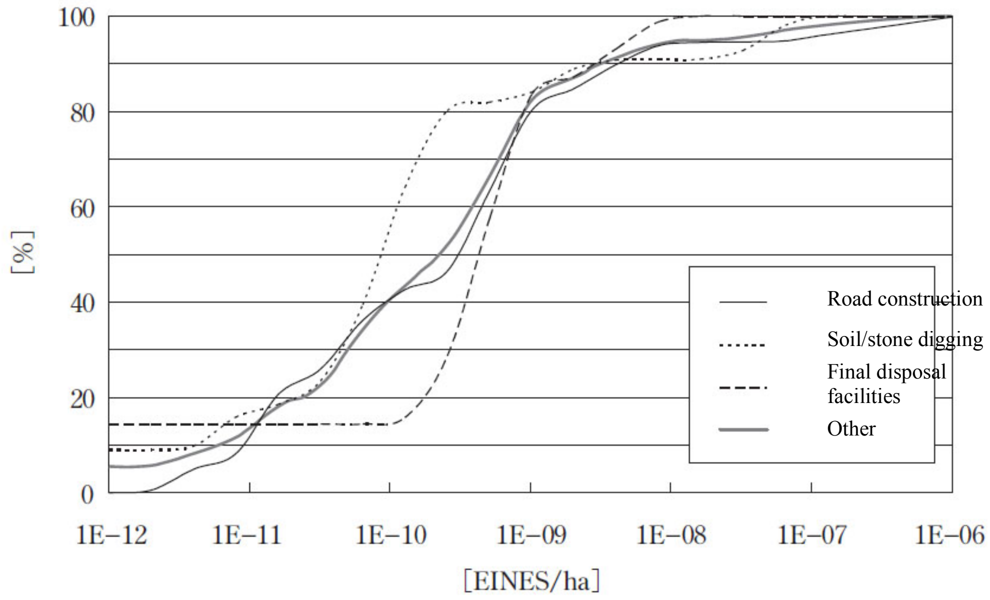


Figure 2.10-9: Cumulative probability distribution of damage factors

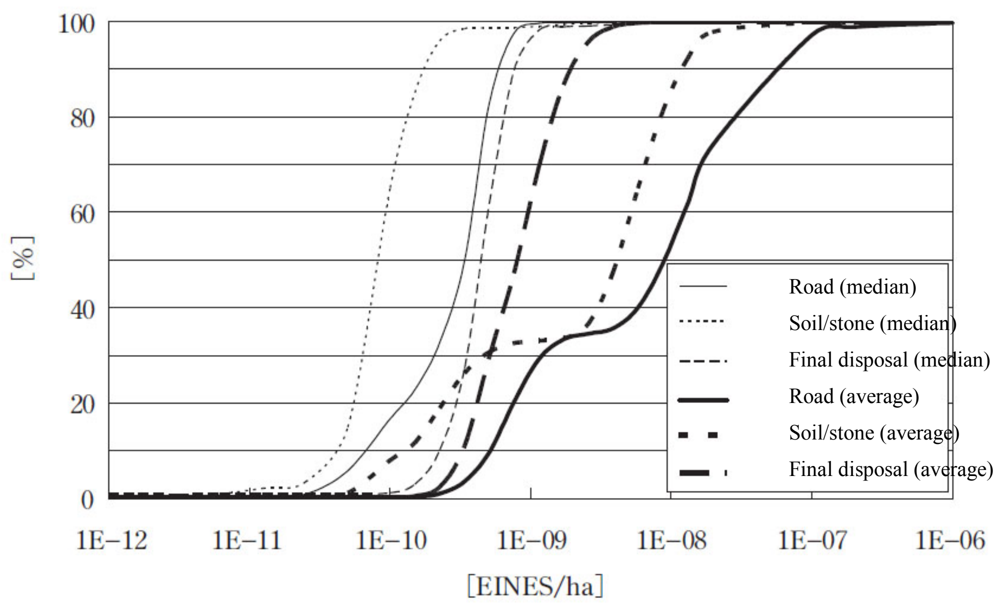


Figure 2.10-20: Cumulative probability distribution of medians and averages of (adjusted) UARs of target cases

The damage factors show wide probability distribution. This is because the large variability among the UAR cases shown in Figure 2.10-13 was reflected as the governing cause (rank correlation coefficient: 0.87 - 0.98). In addition, for reference, Figure 2.10-20 shows the result of estimation of damage factors as the medians and averages of the cases not by the variability distribution of the cases but by the bootstrap method. The width of the estimated medians is narrower than the variability distribution. With regard to road construction and soil and stone digging, because there are cases where UAR is relatively large, the difference between the average and the medial has become large.

With regard to the rank correlation with the variables corresponding to the uncertainty causes of each average and median (Tables 2.10-16 and 2.10-17), although it is common for the estimated error between the average and the median to have great influence due to a limited number of cases subject to assessment, there are differences in the other causes that have great influence. With regard to the averages, the causes that occupy higher ranks are those related to species whose extinction risk is high and whose growth was confirmed in cases where an increment in the extinction risk is high among the cases concerning each type of project, such as *Asarum satsumense* (an EN species whose number of individuals discovered through EIA is large), *A.kiusianus* (although this is a VU species, the number of meshes whose habitats were reported in RDB is only four, of which only one mesh has an identified number of individuals. In this calculation, the number of individuals in Japan was adjusted upward as described in the text of RDB), *Cymbidium macrorhizon* (EN species), and *Elaeagnus matsunoana* (although this is a VU species, the number of meshes whose number of individuals was reported in RDB is only eight and therefore the regions where it is distributed are limited). On the other hand, with regard to the medians, many causes related to species confirmed in two or more cases, such as *Euplectes orix* (VU species), *Calanthe* (VU species), and *Prenanthes tanakae* (VU species), were extracted. These are species whose growth was reported widely in Japan. In addition, the tables show that the estimated error in the parameter *C* (coefficient related to the number of meshes for growth) of the regression equation that estimates the average remaining life expectancy *T* of species, an element of UAR calculation common to each case, has a certain influence.

Although land transformation cases subject to assessment (environmental impact assessment documents) were added under LIME 2, the damage factors have hardly changed from LIME 1 if consideration is given to great differences among cases in the amount of damage per land area (UAR). Although this is mainly because the damage functions have been adjusted by standard values, it is also because the medians of the UARs of the assessment cases were used as the damage factors under LIME 1. With regard to the forms of land use, the representative value of the damage factors for “other (unknown)” is larger than that under LIME 1 (Figure 2.10-21), and the definition of the damage factors for “other” was made simpler under LIME 2 (also see the notes to Table 2.10-15).

Table 2.10-16: Rank correlation coefficients of medians of target case UARs

	Road construction (18 cases)		Soil/stone digging (11 cases)		Final disposal facilities (7 cases)	
#1	No. of assessment cases	0.37	No. of assessment cases	0.34	No. of assessment cases	0.49
#2	C (parameter of T_{reg})	-0.08	T_{sim} (*Calanthe*)	-0.17	T_{sim} (*Euplectes orix*)	-0.18
#3	T_{sim} (*Euplectes orix*)	-0.07	No. of growing individuals of *Calanthe* in an EIA case	0.15	No. of growing individuals of *Euplectes orix* at a point in an EIA case	0.16
#4	T_{sim} (*Polygonaceae*)	-0.07	N_4 (*Calanthe*)	-0.14	N_4 (*Prenanthes tanakae*)	-0.11
#5	*A* (parameter of T_{reg})	-0.04	N_4 (*Calanthe*)	-0.14	N_4 (*Prenanthes tanakae*)	-0.11
#6	N_3 (*Euplectes orix*)	-0.04	T_{sim} (*Euplectes orix*)	-0.13	*C* (parameter of T_{reg})	-0.11
#7	N_3 (*Euplectes orix*)	-0.03	*C* (parameter of T_{reg})	-0.12	N_4 (*Prenanthes tanakae*)	-0.10

- No. of assessment cases: Actually, this indicates the ranking of 1,000 bootstrap samples prepared beforehand (because the ranking is arranged by the use of the averages of re-sampled cases, it is not necessarily appropriate for examining rank correlation of medians).
- *A* and *C* are parameters of the regression equation for the calculation of *T*, the average remaining

life expectancy of species. N_x is the estimated number of individuals in meshes with the rank x in the number of growing individuals (see Table 2.10-10).

- T_{sim} corresponds to uncertainty caused by the distribution of rates of variability in the number of individuals (f_m) when T is estimated by simulation.

Table 2.10-17: Rank correlation coefficients of averages of target case UARs

	Road construction (18 cases)		Soil/stone digging (11 cases)		Final disposal facilities (7 cases)	
#1	No. of assessment cases	0.78	No. of assessment cases	0.88	No. of assessment cases	0.85
#2	T_{sim} (*Asarum satsumense*)	-0.20	T_{sim} (*Cymbidium macrorhizon*)	-0.20	No. of growing individuals of *Elaeagnus matsunoana* in an EIA case	0.18
#3	N_3 (*A. kiusianus*)	-0.17	N_2 (*Cymbidium macrorhizon*)	-0.09	No. of points of growth of *Heterotropa savatieri* in an EIA case	0.14
#4	N (*Asarum satsumense*)	-0.12	N_2 (*Cymbidium macrorhizon*)	-0.08	N_3 (*Elaeagnus matsunoana*)	-0.10
#5	T_{sim} (*A. kiusianus*)	-0.08	N_2 (*Cymbidium macrorhizon*)	-0.08	N_3 (*Elaeagnus matsunoana*)	-0.09
#6	N_2 (*A. kiusianus*)	-0.05	N_2 (*Cymbidium macrorhizon*)	-0.08	N_3 (*Elaeagnus matsunoana*)	-0.09
#7	A (parameter of T_{reg})	-0.04	N_2 (*Cymbidium macrorhizon*)	-0.08	T_{sim} (*Elaeagnus matsunoana*)	-0.08

- No. of assessment cases: Actually, this indicates the ranking of 1,000 bootstrap samples prepared beforehand (ranking arranged by the use of the averages of re-sampled cases).
- A is a parameter of the regression equation for the calculation of T, the average remaining life expectancy of species. N_x is the estimated number of individuals in meshes with the rank x in the number of growing individuals (see Table 2.10-10). N is direct assessment of the number of individuals in Japan, not adding up of N_x.
- T_{sim} corresponds to uncertainty caused by the distribution of rates of variability in the number of individuals (f_m) when T is estimated by simulation.

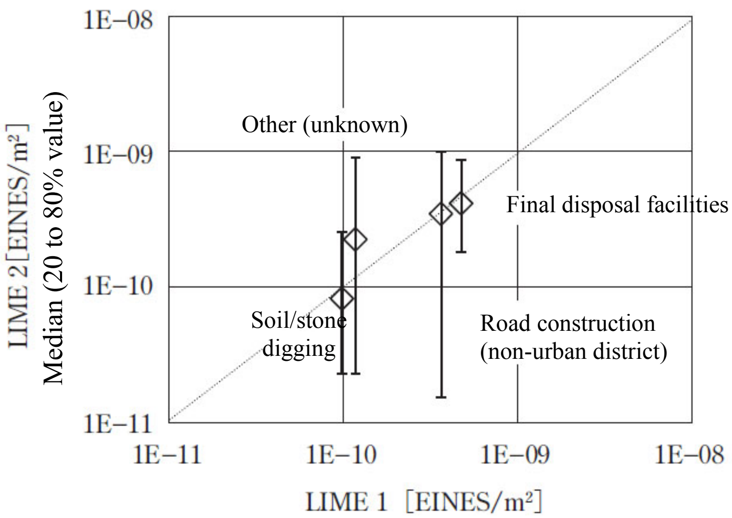


Figure 2.10-21: Comparison between LIME 1 and LIME 2 (damage factors for biodiversity)

2.10.4 Procedure for impact assessment of land use

Figure 2.10-5 shows the framework of damage assessment of land use under LIME. Concrete procedures for the characterization and damage assessment of land use are as described below.

The inventory of land use is expressed by the occupation time $Inv_{time}^{Occ}(a)$ [yr] and the occupation area, $Inv_{area}^{Occ}(a)$ [m^2] in the form of land use *a* and the area of transformation from *b* to *a*, $Inv_{area}^{Trans}(b,a)$ [m^2].

During the procedure for characterization, with regard to occupation and maintenance each, a category indicator *CI* is calculated by the use of the inventory data and the characterization factor CF^{Occ} (*a*) or CF^{Trans} (*b,a*) as follows:

$$\text{Land transformation: } CI^{Trans} = \sum\nolimits_{b,a} Inv_{area}^{Trans}(b,a) \tag{2.10-7}$$

$$\text{Land occupation: } CI^{Occ} = \sum\nolimits_{a} Inv_{area}^{Occ}(a) \times Inv_{time}^{Occ}(a) \tag{2.10-8}$$

Actually, however, because difference in the degree of impact due to difference in the form of land use is ignored and *CF* is fixed at 1, it is all right to simply add up the areas (× time) entered in the inventory.

The procedure for assessment of damage to the object of protection in primary production is carried out as follows: regarding occupation, the amount of damage is calculated by multiplying the occupation area and time by $DF_{NPP}^{Occ}(a)$, the damage function corresponding to the type of current land use; regarding transformation, the amount of damage is calculated by multiplying the area of land transformation by $DF_{NPP}^{Trans}(b,a)$, the damage function corresponding to the type of land use before and after the transformation (before transformation *b*; after transformation *a*). The total of the two amounts of damage is the amount of damage to the object of protection. The damage index of primary production DI_{NPP} is expressed by the following equation:

$$DI_{NPP} = \sum\nolimits_{a} DF_{NPP}^{Occ}(a) \times Inv_{area}^{Occ}(a) \times Inv_{time}^{Occ}(a) + \sum\nolimits_{b,a} DF_{NPP}^{Trans}(b,a) \times Inv_{area}^{Trans}(b,a) \tag{2.10-9}$$

The assessment of damage to the object of biodiversity protection is carried out concerning transformation. The amount of damage is calculated through multiplication by $DF_{EINES}^{Trans}(a)$, the damage function corresponding to the type of land use after transformation. The damage index of the extinction risk DI_{EINES} is expressed by the following equation:

$$DI_{EINES} = \sum\nolimits_{b,a} DF_{EINES}^{Trans}(a) \times Inv_{area}^{Trans}(b,a) \tag{2.10-10}$$

Based on these damage factors of these types of land use, LIME provides the damage factor per resource consumption or amount of final disposal of waste in other impact categories of resource consumption and waste disposal. Even if the area of land use is not calculated in the inventory, it is possible to carry out impact assessment based on resource consumption or the amount of final waste disposal. By contrast, if both the area of land transformation and the amount of final waste disposal are entered in the inventory as basic flow, because the amounts of damage are counted double if the damage factors for primary production and biodiversity in both impact categories are applied simultaneously, it is necessary to apply only one of them.

In the case of integration, the resultant factors from monetary conversion or non-dimensionalization of impact on biodiversity or primary production, $\underline{IF_{NPP}^{Occ}(a)}$, $\underline{IF_{NPP}^{Trans}(b,a)}$ and $\underline{IF_{EINES}^{Trans}(a)}$, are used. The single index *SI* can be gained by the use of these integration factors and the inventory of land use – that is, the area of land transformation/occupation, $Inv_{area}^{Trans}(b,a)$ or $Inv_{area}^{Occ}(a)$, and the occupation time $Inv_{time}^{Occ}(a)$.

$$SI = \sum_a IF_{NPP}^{Occ}(a) \times Inv_{area}^{Occ}(a) \times Inv_{time}^{Occ}(a) + \sum_{b,a} IF_{NPP}^{Trans}(b,a) \times Inv_{area}^{Trans}(b,a) + \sum_{b,a} IF_{EINES}^{Trans}(a) \times Inv_{area}^{Trans}(b,a) \tag{2.10-11}$$

The characterization factors CF^{Occ} (a) and CF^{Trans} (b,a) are attached hereto as A1, and the damage factors $DF_{NPP}^{Occ}(a)$, $DF_{NPP}^{Trans}(b,a)$, and $DF_{EINES}^{Trans}(a)$ are attached hereto as A2. The integration factors $IF_{NPP}^{Occ}(a)$, $IF_{NPP}^{Trans}(b,a)$, and $IF_{EINES}^{Trans}(a)$ are attached hereto as A3.

Acknowledgment

When we developed the damage functions of land use, we received a lot of valuable advice on assessment related to primary production from Prof. Yasuoka Yoshifumi of the Institute of Industrial Science, the University of Tokyo (now, Director of the National Institute for Environmental Studies), and Associate Prof. Tsunekawa Atsushi of the Graduate School of Agricultural and Life Sciences, the University of Tokyo (now, professor of the Arid Land Research Center, Tottori University). During the assessment related to the extinction risk, we received great and detailed guidance from Prof. Matsuda Yunosuke of the Ocean Research Institute, the University of Tokyo (now, professor of the Graduate School of Environment and Information Science, Yokohama National University). However, we made changes in the simulation model for calculating the extinction probability, estimated the parameters of the statistical model of average remaining life expectancy by regression analysis, using the calculation results, and introduced the adjustment by standard values according to our own demand and judgment. With regard to the Chikugo model, we received guidance from Mr. Seino Hiroshi, Director of the National Agriculture and Bio-oriented Research Organization. Prof. Yahara Tetsukazu of the Kyushu University gave us cooperation concerning published RDB data. We would like to thank all of them for their support.

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2.11 Resource consumption

Changes under LIME 2

- Uncertainty assessment of damage factors was carried out. The uncertainty of the damage factors for biodiversity and primary production included geographical variability (assessment of the uncertainty about at what point the resource gathering entered in the inventory), and the uncertainty of the damage factors for social assets included temporal variability.
- The parameters used for the calculation of the area of land used for the mining of mineral resources were updated through a review of the base data, using information on the grade of each mine and the stripping ratio for typical metals. With regard to uranium, such data were collected and arranged and then added to the list of damage factors.
- The parameters for the calculation of the damage factor for social assets (user cost) were updated based on databases and literature research covering recent years.
- Because the damage functions for the impact category of land use were used as some of the damage functions of biodiversity and primary production, a review of the impact category of land use has been reflected in LIME 2.

2.11.1 What phenomenon is the environmental impact of resource consumption?

(1) Range and categories of resources dealt with by LCA

Generally, the word "resources" is used widely. For example, there are such expressions as human resources and tourism resources. However, what is measured under LCA is mainly the flow of substances or energy. Therefore, it is appropriate to assume the following resources from the viewpoint of LCIA: (1) fossil fuels; (2) mineral resources; (3) stone resources (for the purpose hereof, the resources listed as (1) to (3) are classified as exhaustible resources, which may sometimes be written as non-biological resources); (4) biological resources (forest resources, aquatic resources, and other recyclable resources); (5) water resources; (6) land (space) and solar energy (resources that are virtually inexhaustible but have quantitative limitations).

For the purpose hereof, (2) mineral resources are used for extracting specific ingredients (such as metals and fertilizers), while (3) stone resources are used mainly for purposes that use the properties of stone itself.

Although stone resources are quantitatively larger than fossil fuels and mineral resources, it cannot be said that they are socially inexhaustible, given that the minable amount is virtually limited due to legal regulations for the protection of nature.

If physical or technical depletion of resources is a problem for LCA, considering the resources listed in (1) to (6) above, in that order, as the scope of assessment seems to correspond to the inventory analyses carried out so far. Although "since the dawn of history, there has been no report about resources (mineral resources) becoming impossible to supply due to depletion" (Nishiyama 1993), because there are global problems, such as the destruction of tropical forests (forest resources) and indiscriminate fishing of aquatic resources, it is an important challenge to incorporate the assessment of the impact of consumption of "renewable resources" and "aquatic resources" into the LCIA method. With regard to land, not depletion (quantitative decrease) but deterioration (qualitative decrease) or competition may become a problem (see 2.10 “Land use” also).

(2) Causal relationship of environmental impact concerning resource consumption

First of all, the impact of resource consumption as a problem for LCA is a decrease in the amount of resources usable for future generations and the impact of the decrease. There is the view that this is a problem concerning resources and energy and is not an environmental problem in a narrow sense. Therefore, we will try to show the causal relationship of the impact of resource consumption after arranging the relationship between resource consumption, environmental impact and LCA.

Nishiyama (1993) pointed out that the uniqueness of resources is “limitedness” and “maldistribution,” which have caused the longstanding problem of resource depletion, various kinds of social anxiety, and wars.

By reference to Fukami et al. (1996), what is recognized as “resources problems” at present can be roughly divided into “physical depletion,” “problems related to stable supply (such as artificial interruption),” and “environmental problems that accompany supply and resource consumption.”

For the purpose of LCA, assessment is frequently made by calculating the input of resources and energy as the basic flow of input and setting impact categories that focus on resources and energy themselves. This is a general practice derived from the history of development of LCA. Assessment has frequently focused on the below-described reserves, which just means that the impact of resource consumption on “physical depletion” has been treated as a problem to be picked up for LCA from the viewpoint of scarcity of resources or usability in the future – that is, “limitedness of resources.” This can be said to be the viewpoint of sustainability, which includes the viewpoint of intergenerational, and sometimes regional, equity.

However, “depletion” is a far longer-term problem than “stable supply.” If the possibility of impact on society is taken into consideration, it can be thought that the “problem of stable supply” will first become an actual problem. For example, there may be a situation where Japan cannot secure sufficient supply of a certain kind of resource even if the resource is supplied well in neighboring countries. However, although the problem of stable supply is caused by a political factor or such a factor as a natural disaster, the impact of the problem spreads or arises within the market economy (see Column 2.11-1). Given these characteristics, it is hard to think that the viewpoint concerning the problem of stable supply should be assessed by LCIA as an environmental impact.

Another important viewpoint is the environment impact that accompanies the supply and consumption of resources. Given that some kinds of pollution caused by the development of mining in Japan gave serious damage to the mining industry in many cases, it seems clear that it is important to assess this problem by LCA. However, whether this should be directly set up as an impact category for an LCIA method system is another problem.

For example, emissions of carbon dioxide due to combustion of fossil fuels – that is, “resource consumption” – are usually dealt with in the impact category of global warming (climate change). If this is dealt with in the impact category of “resource consumption,” an extremely large number of environmental burdens must be dealt with in the impact category of "resource consumption." To put it another way, it is possible to have the view that all the environmental problems related to this aspect should be dealt with in impact categories other than resource consumption. In other words, what interaction with the environment should be included in the impact category of resource consumption is the problem concerning the division between the border of input/output items established by the LCI side and the border presupposed by the LCIA side.

Idealistically, it is desirable for LCA researchers or LCI databases to supply information on all the environmental burdens to be analyzed in connection with the consumption and supply of resources (such as harmful drainage or changes in the ground surface due to mining). Because this will make it sufficient to connect them with the impact category of "toxic chemicals" or "land use" at the stage of LICA, it is all right to deal only with the problems of depletion and rarity in the impact category of "resource consumption" in the LCIA method system. This seems to become the clearest arrangement.

However, if existing LCI databases do not provide full information that can be connected to the environmental impact presupposed as important under a certain LCIA method system, the realistic solution is that the LCIA method system side should connect with information provided from the LCI databases by positively incorporating these categories. How this portion is treated during damage assessment under LIME will be described in 2.11.3.

Based on what has been described above, Figure 2.11-1 shows the environmental impacts related to resource consumption that may be taken into consideration during LCIA.

Column 2.11-1

A case of assessment of the impact of interruption in the stable supply of resources

In Japan, the impact of interruption in the stable supply of resources was assessed in the "Research on the Impact of Interruption in the Supply of Main Mineral Resources in the Japanese Economy" (March 2002), which the Mining and Materials Processing Institute of Japan carried out by commission from The Research Institute of Economy, Trade and Industry, based on discussions at the "Mineral Resources Policy Platform." The research dealt with copper, cobalt, and tantalum and consisted of a review of a supply interruption scenario based on a survey on supply-demand trends, simulation based on a multilateral general equilibrium model, and a price spread analysis that used the inter-industry relations table for analysis of resources.

The impact of supply interruption that was considered in the research was the spread from price impact and supply volume limitation to a decrease in corporate competitiveness. The main measures discussed in it focused on the supply side, such as mining and storage, and economic and social changes in the world as a factor for supply interruption (at least in the short term (Kojima 2002)).

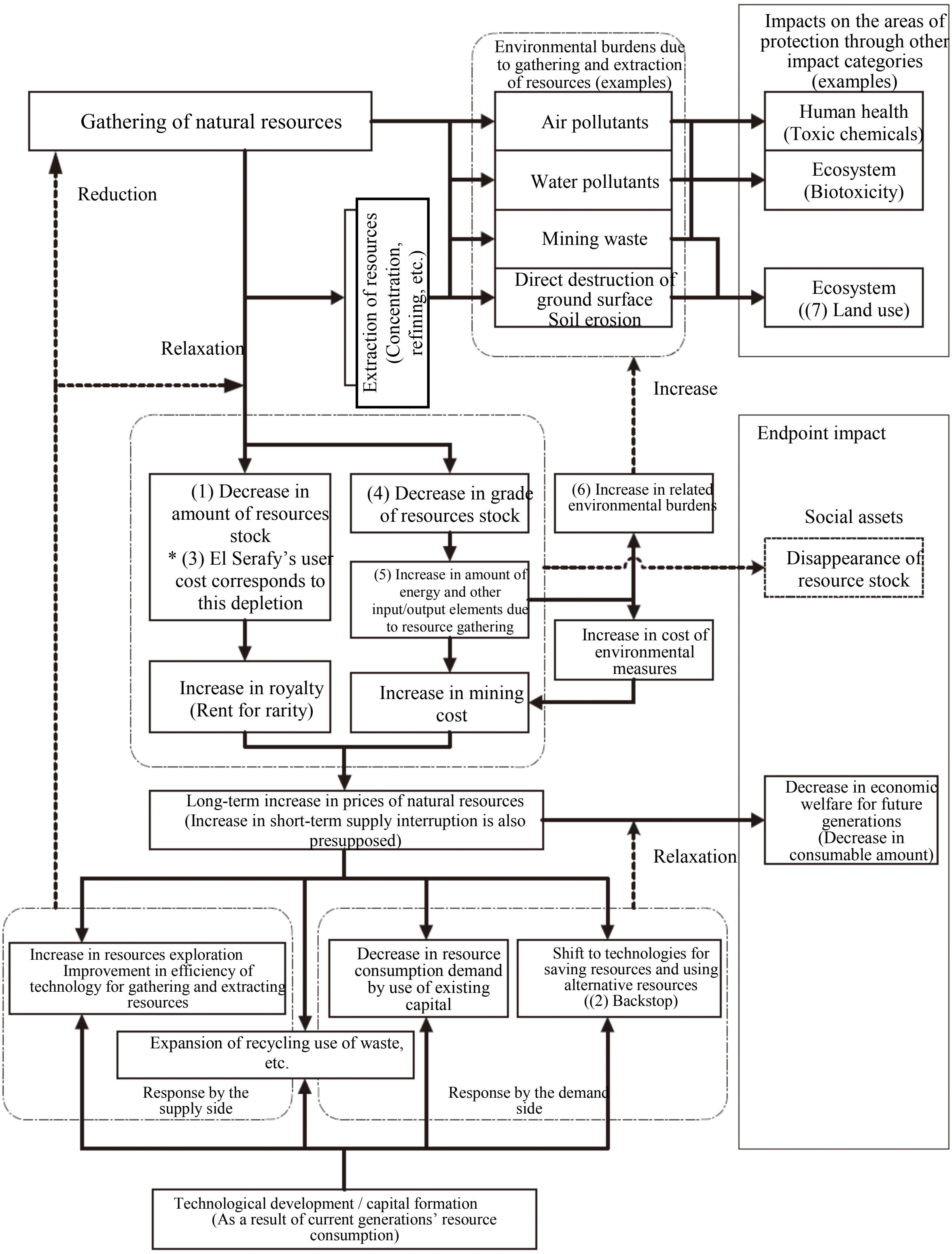


Figure 2.11-1: Causal relationships of resource consumption

(1) to (7) in the figure are numbers used for reference in 2.11.2 (1).

(3) Endpoint of the environmental impact of resource consumption

a. Impact of resource gathering on human health and the ecosystem

According to the Environment Agency (1990), there are the following three main environmental impacts of underground resource gathering: "(1) direct destruction of ground surface; (2) water pollution, air pollution, and soil erosion due to mining and refining; and (3) production of a large quantity of mining waste."

With regard to (1), open-pit mining destroys a wider area of ground surface than does underground mining and requires the storage of a large quantity of overburden. Because deposits of iron ore and bauxite expand widely and are located relatively near to ground surface, they are frequently mined in open pits. In the case of other metal ores also, if a large-scale and low-grade deposit lies near the ground surface, open-pit mining is economically advantageous (Craig et al. 2001; Kesler 1994; Pipkin et al. 2004).

With regard to (2), especially if high-sulfur coal or pyrite is mined, drainage from the acid mine may continue for hundreds of years. This not only influences pH but also has great impact on aquatic organisms through leaching out of iron, zinc, copper, and other toxic metals (Pipkin et al. 2004).

With regard to (3), waste other than overburden is produced. For example, if lead, zinc, copper, or other sulfide is extracted from ores (crude ones), the flotation method is used and produces residues (tailings), whose disposal requires a sediment pond.

Including these impacts and those that may arise unless appropriate measures are taken, many potential impacts have been pointed out as shown in Table 2.11-1.

Table 2.11-1: Potential environmental impacts of the mining industry

Impacts on the natural environment	Pollution impacts
• Destruction of natural habitats (growing/habitat environment) in mining sites and waste disposal sites • Destruction of neighboring habitats as a result of drainage and discharge • Destruction of neighboring habitats due to a rush of settlers • Changes in river forms and river ecology due to changes in silt and flow • Changes in groundwater surface • Changes in land form • Deterioration of land due to inappropriate restoration after closing • Unstableness of land • Risk of accidents in structures and dams • Abandoned equipment, factories, and buildings	• Drainage from mining sites (including drainage from acid mines and drainage piped up in mines) • Outflow of sediment from mining sites • Pollution by mining on riverbed • Outflow from processing of minerals • Outflow of polluted water from sites • Leakage of oil and fuel • Soil pollution by leakage of processed residues and chemicals • Leaching out of pollutants from tailings and disposal areas • Air pollution by disposal of minerals • Discharge of fine particles from sites near residential areas or habitats • Discharge of methane from mines

Translated from UNEP (2000); however, the description of impacts related to working environments was omitted.

b. Impact of resource stock depletion and deterioration on social assets

If attention is given to the process through which the depletion and deterioration of resource stock decreases the availability of resources for future generations, it can be thought that the endpoint of the impact is economic damage to future generations. Concretely, how should this be understood?

If the supply of oil suddenly stops, society will be confused and receive a great influence. However, long-term exhaustion of resources differs from a sudden accident. If the price of an exhaustible resource gradually increases over a long time, search for the resource may become eager and the amount of deposit may increase to keep up with economic demand. In addition, the development of resources substitutable for the resource may be promoted, with the result that the depletion of the resource may be delayed. In this case, it can be predicted that the price of the resource will not exceed the prices of the substitutable resources (backstop). Moreover, if recycling is promoted thoroughly, the problem as to whether or not the underground deposit of a resource may be depleted will become unimportant.

According to the theory of resource economics, it is necessary to consider user cost in addition to the actual costs necessary for mining, such as the personnel cost. If an exhaustible resource is mined at present, it will become impossible to mine it in the future. The opportunity cost lost due to this (impact on future profits) is the user cost. It can be thought that the marginal user cost is the royalties that the miner pays to the owner of the resource (rent for rarity). From the viewpoint of maximization of the current value of resource stock, the most favorable approach is to fix output for each period so that the marginal user cost will increase at a rate equal to the interest rate (Hotelling's Rule). However, the current prices of resources do not have such upward trends caused by rarity (according to an analysis by researchers of the US Geological Survey, the prices of mineral resources decreased as a whole in the 20th century) (Sullivan et al. 2000). Some researchers have pointed out that the price of a resource may rise sharply when depletion becomes imminent (Yasui 2000; Daly et al. 2003). In addition, if miners actually take user cost into consideration, the stock of a resource for future generations will still decrease. There is the view that thinking of the intergenerational allocation of exhaustible resources as a utilitarian optimum problem has a bias favorable to the current generation, because future generations' utility is discounted (Washida 1992).

In addition to such factors related to rarity, it can be thought that the mining of a resource might increase mining cost due to a reduction in the grade of the remaining stock or the necessity for mining it at more remote places.

With regard to the problem of resource depletion, many experts in the fields of resource geology and resource economics in Japan have the following view: although mineral resources can be mined (no depletion of the mineral resources) if a decrease in the grade of ores (target metals) is allowed, the amount of energy necessary for concentration and refining and the amount of waste produced through the processes will become huge, with the result that the resources will not be economical (Tachimi 1986; Sato 1992; Nishiyama 1996).

For example, Sato (1992) dealt with the problem of mineral resources in the 21st century. He concretely discussed "the relationship with energy, the most important element for thinking about future mineral resources whose grade will become lower," and predicted that if inexpensive energy can be supplied sufficiently, the depletion of mineral resources that will threaten human civilization will not physically occur in the 21st century.

In the next section, when the characterization factors of resource consumption are discussed, assessment indexes will be explained from the viewpoint of rarity. At present, there is no index or method that has been widely agreed upon for the calculation of the amount of impact of resource consumption caused from rarity (from the standpoint that the amount has not been fairly (or sufficiently) evaluated at a simple market price).

2.11.2 Characterization of resource consumption

(1) Existing characterization factors of resource consumption

The characterization factors of resource consumption are based on the following three viewpoints:

(1) Assessment from the viewpoint of rarity, focusing on the amount of resources
(2) Assessment from the viewpoint of rarity (or "value" of resources), focusing on energy or cost
(3) Assessment from the viewpoint of environmental impact, focusing on resource gathering (including relevant acts of altering nature)

a. Resource depletion: the characterization factor that focuses on the amount of resources (corresponding to Figure 2.11-1 (1))

Both minerals and fossil fuels are deposited underground and their amounts are limited. The characterization factor that focuses on this limitedness consists of indexes that combine the following: (1) ultimate resources (*U*); (2) minable reserves (*R*); and (3) production volume (*P*) (for the terms that represent the amount of resources, see Column 2.11-2).

Guinée et al. (1995) suggested that the abiotic depletion potential (ADP) should be used as the characterization factor that focuses on the amount of abiotic resources.

$$ADP_i = (P_i / U_i^2) / (P_{Sb} / U_{Sb}^2) \quad (2.11\text{-}1)$$

P_i and U_i are the production volume of the abiotic species i [kg yr^{-1}] and the resources of i [kg], respectively. P_{sb} and U_{sb} are P and U of the standard substance (antimony), respectively. Guinée et al. call U "ultimate reserve." This is the value calculated by audaciously regarding the amount existing in the crust with a certain thickness (10 km). Guinée et al. (2001) first recommended this as the characterization factor of abiotic resources (After that, the value of ADP was revised) (van Oers et al. 2002). In the Japanese language, because "resources" may not be confused with "the amount of resources" as the name of the impact category of LCIA or the target element of impact assessment, "reserves" sometimes means "the amount of reserves" in this text.

On the other hand, it is impossible for humankind to mine all the ultimate reserves. Because assessment should be made based on the profitable amount of deposit, if the minable amount is used as the base, characterization factors that include R and P, such as $1/R$ and P/R^2, deserve to be considered.

Column 2.11-2

Terms that represent the amount of resources

Various terms are used for representing the amount of resources on earth. For example, they can be divided according to the degree of geological knowledge or economy as shown in Table 2.11-A. Minable reserves refer to the amount of economically minable reserves of the existing resources. If the economically minable amount in the near future is added to the existing amount, this is called “reserve base.” Reserves change when a new mine is discovered or technology progresses.

On the other hand, the ultimately minable amount of resources, including unidentified resources, is called “ultimate resources.” In the case of mineral resources, ultimate resources have been estimated by the use of global chemical knowledge, such as crustal abundance.

Table 2.11-A: Classification of ultimate resources

		Identified mineral resources			Potential mineral resources	
		Identified		Inference	Degree of certainty	
		Close estimate	Rough estimate		Hypothetical	Purely physical
Economical		Reserves		Inferred reserves		
Subeconomic	Marginally economic	Marginal reserves		Inferred marginal reserves		
	Subeconomic					

- Extracted from the classification table of ultimate resources in Nishiyama (1996); some terms altered according to the text.
- The horizontal axis indicates geographical certainty, while the vertical axis indicates economy. There is an attempt to systemize this classification method by adding the amount of waste and the available amount (amount of stock, stockpiles) as a row (Nishiyama 1996). In addition to geological reliability and economy, legal and environmental limitations must be considered as an axis that is excluded from reserves and included in resources (Craig et al. 2001).

Any of them has the advantage of being able to consider many kinds of resources. On the other hand, the (minable) reserves *R* changes, depending on the amount of newly discovered resources. Because of this, it has been pointed out that although the minable years (*R/P*) of four kinds of metals, such as gold, were less than 20 years in 1970, it has been pointed out that they increased by 20% to 110% in 1990 (on the other hand, although the minable years of four kinds of metals, such as zinc, were 20 to 40 years in 1970, they decreased by 19% or remained the same) (Nishiyama et al. 1993). In addition, the production volume *P*, whose exponential increase often causes anxiety as a factor for resource depletion, changes as a matter of course. Therefore, it is necessary to note that these indexes change according to technology and resource price. Because it has been pointed out for these reasons that the number of minable years cannot be used as a standard for resource depletion (Shouji et al. 1997), it is difficult to select an index that can be recognized widely as the characterization factor that focuses on the amount of resources.

In addition to the above-described static indexes, the following indexes have been recommended, although their use as characterization factors was not originally recommended: the increase rate of reserves; the increase rate of life cycle efficiency with the progress in technology; the increase rate of final demand; and the current “degree of gap” of the mining speed from the “limit of sustainability” calculated based on the recycling rate, the improvement rate, etc. (Matsuhashi 1996).

With regard to the trends after the development of LIME 1 in Japan, the Ministry of the Environment calls the harmonic average of the “acceleration of resource depletion” in terms of volume of iron and the “market price” (normalized by iron) the “resource depletion characterization factor” in the Ministry of the Environment’s product environment information system (eco sele), and attention has paid to the use of it for providing information through a radar chart that consists of the following three axes: global warming; resource consumption; and the use and management of chemicals. Although the market price is the “parameter indicating resource consumption,” there are many cases where correlation with resource depletion cannot be kept only by the price. Therefore, the Ministry of the Environment considered using the characteristic coefficient as the parameter indicating resource consumption by adjusting it with the value of “acceleration of resource depletion” into which the impact on the basis of resource consumption is incorporated (Product Environment Information System Secretariat 2005).

“Resource depletion acceleration” is an index recommended by the Ecomaterials Center of the National Institute for Materials Science. Its details are written in a report (National Institute for Materials Science 2004) and can be outlined as follows: The resource depletion velocity *V*, the general assessment index (assessment function), is

$$V \;\; [1/t] \;\; = \frac{(\text{Consumption speed} \;\; D_i[M/\text{t}]) - (\text{reproduction speed} \; [M/\text{t}])}{(\text{Resource stock (reserves)} \;\; R_i[M])} \tag{2.11-2}$$

If the resource *i* is used at a certain speed for *n* years, how much is *V* accelerated? If *V* is differentiated and minute terms are ignored, the resource depletion acceleration C_i can be calculated as follows:

$$C_i = \frac{K}{R_i} \times \left(1 + \frac{n}{\lambda_i}\right) \tag{2.11-3}$$

In this equation, λi is the number of durable years ($Ri \div Di$) and *K* is a constant. The characterization factor is the result of the following equation, which normalizes the factor in terms of iron:

$$Ci \; (\text{resource depletion acceleration in terms of volume of iron}) = \frac{R_{Fe}}{R_i} \times \left(1 + \frac{n}{\lambda_i}\right) \Bigg/ \left(1 + \frac{n}{\lambda_{Fe}}\right) \tag{2.11-4}$$

Although *n* depends on product, it is fixed at “100 years, the number of years used for discussions about sustainability for the time being.”

b. Resource depletion: characterization factor that focuses on energy and cost

Energy and cost are necessary for mining minerals and fossil fuels. Moreover, because mining is carried out at mineral deposits where minerals of high purity can be mined easily, mining and refining efforts to gain desirable resources increase, resulting in an increase in consumed energy and a decrease in the grade of gained resources. In addition, because fossil fuels themselves have the aspect of energy, the amount of heat generation [MJ kg^{-1}] seems to be the clearest index for considering the aspect of energy.

Finnveden (1996) used exergy (theoretical maximum value of energy that can be extracted externally when heat energy under certain temperature and pressure conditions is transferred to other conditions; also called “available energy”) to calculate the characterization factors of some kinds of minerals and fossil fuels. Although the value of exergy is highly reliable, there is doubt that the value of a kind of mineral can be measured by exergy. This is because the rarity of resources is not taken into consideration at all.

Column 2.11-3

Weak sustainability and strong sustainability
The methods for quantitative assessment of resource consumption include methods whereby some canonicity related to sustainability is introduced and simple assessment indexes are defined. Like the case explained in 2.11.2 (1), one of such methods assumes a certain backstop resource as a substitute and uses the price of the resource for assessment. In such a case, one of the issues is to what extent the substitution of the consumed resource should be considered (allowed). Kanamori et al. (2002) think that, under “weak sustainability,” “if an environmental resource is depleted and degraded, it can be substituted by another form of resource (human, economic).” On the other hand, they think that, under “strong sustainability,” “the bad effect of the depletion and degradation of the ecosystem on human society (especially, the poor and future generations) is difficult to compensate by artificial means and therefore resources should be used without giving damage to the physical structure and functions of the ecosystem, for the benefit of both intergeneration fairness and intra-generation fairness.” It can be thought that many methods explained in this section (user cost and surplus energy) are based on “weak sustainability.”

Steen (1999) recommended the cost of mining [amount of money kg^{-1}] as the characterization factor. Steen suggested that a substitute resource that can be used sustainably (as backstop) should be assumed (corresponding to Figure 2.11-1 (2)) and that the total of the cost of producing the substitute resource and the social cost accompanying the production should used as the weighted factor for the resource. As examples of substitute resources, crude oil is substituted by canola oil, and coal is substituted by charcoal. On the other hand, under LIME, the below-described El Serafy’s “user cost” (Figure 2.11-1 (3)) has been adopted for assessing the social assets that are protected against resource consumption. This is assessment on the assumption of loose substitutability (weak sustainability) between natural resources and other assets (see Column 2.11-3).

Müller-Wenk (1998) suggested an assessment method based on “surplus energy” for gathering resources – mainly, mineral resources. Surplus energy indicates the loss of energy due to future generations’ use of lower-grade resources (Figure 2.11-1 (4)) as a result of the current generation’s giving priority to the mining of higher-grade minerals according to economic principles (a part of Figure 2.11-1 (5)). Moreover, Müller-Wenk (1998) increased the current inventory (environmental burden and consumption of energy resources) of gathering resources by the amount of surplus energy (“hypothetical environmental impact”). As a result, Müller-Wenk concluded that this additional environmental burden (Figure 2.11-1 (6)) was small.

On the other hand, although Goedkoop et al. (2000) based their approach on Müller-Wenk's research, they pointed out that Müller-Wenk's calculation process included arbitrary setting of parameter values. They adopted excess energy [MJ kg^{-1}] itself as the damage index (therefore, with regard to the impact assessment result by Eco-indicator 99, excess energy and the amount of consumed energy in the inventory should not be compared or added simply) and recalculated the assessment coefficient, including fossil fuels. For example, the excess energy of fossil fuels is assessed on the assumption of substitution with shale oil (alternative resources may change with the subjectivity of evaluation/selection of a viewpoint).

Clearly, excess energy can be used as an index, for it can assess the impact of resource consumption on human society. In addition, as described above, Japanese experts in resource geology and resource economics used the results of analysis by Page et al. (1975) and had similar discussions (Nishiyama 1993; Washida 1992; Tachimi 1986; Nishiyama 1996). At present, however, basic data available for assessment are insufficient and it is difficult to offer highly precise characterization factors concerning many kinds of resources. Moreover, it is extremely difficult to create a framework for systematic assessment of the impact, combining the impact on the current generation with that on future generations.

c. Resource gathering: the characterization factor that focuses on the scale of alteration to nature that accompanies resource gathering

The World Resource Institute (WRI) (1997) and Harada et al. (2001) presented and estimated the total material requirement (TMR) of substances related to the acquisition of unit amounts of minerals and fossil fuels. In addition, under LIME, the area of land use for mining of each kind of mineral or fossil fuel was calculated during damage assessment (Figure 2.11-1 (7)). It may be possible to make these indexes relative and use them as characterization factors, regarding them as substitute indexes of nature alteration.

(2) Characterization factor of resource consumption under LIME

From the viewpoint of the "resource and energy problem" that concerns a decrease in the availability of resources for future generations, it may be possible to use indexes focusing on the amount of resources, such as the number of minable years, or adopt the above-described excess energy or the amount of damage to social assets for the purpose of damage calculation.

Because mining from underground is common to both mineral resources and energy resources (fossil fuels), it seems desirable that the characterization factor should be applicable to both. However, the amount of energy resources (fossil fuels) is limited in terms of humankind's temporal axis, and energy resources disappear after use (burning). On the other hand, many kinds of mineral resources can be recycled from products and it may become possible to extract mineral resources from low-grade deposits by additional input of energy. Because of this great difference between the two, there is the view that it may be necessary to adopt a characterization factor which takes such difference into consideration.

The metal weights (annual domestic consumption of natural resources) were calculated based on the website of the Ecomaterials Center of the National Institute for Materials Science (http://www.nims.go.jp/ecomaterial/center/ecoinfo/), "Mining Industry Handbook FY2001" (Research Institute of Economy, Trade and Industry 2001), "Trade Trends Database 2001" (Ministry of Economy, Trade and Industry 2001), etc.

Table 2.11-2: Possible characterization factors compared and examined under LIME 1

Viewpoint for assessment / Type of exhaustible resource	Amount of resource	Alteration to nature due to mining (substitute index)	Specificity of energy resources
Mineral resources (metals)	1/*R*	TMR (WRI (1997); Harada et al. (2001))	
Fossil fuels	P/R^2	Area of land alteration	Heat value

Table 2.11-3: Domestic consumption of natural resources (metal weight) × ranking of results of possible characterization factors and percentage distribution of total

Ranking	1/*R* [%]		P/R^2 [%]		TMR-WRI [%]		TMR-Harada et al. [%]		Land alteration [%]		Metal weight [%]	
1	Ag	18.4	Ag	30.7	Fe	40.4	Fe	24.6	Cu	41.8	Fe	92.9
2	Sb	13.8	Sb	13.2	Cu	34.5	Ag	23.2	Fe	15.3	Al	2.9
3	Ni	9.9	Au	10.6	Sn	10.2	Cu	22.8	Sn	12.6	Cu	1.5
4	Mo	8.5	Cu	7.9	Au	4.5	Au	18.0	Al	8.8	Mn	0.8
5	Cu	8.0	Zn	7.9	Ag	3.1	Ni	2.7	Au	6.9	Zn	0.7
6	Au	7.4	Sn	6.0	Ni	2.4	Mo	2.6	Ag	5.9	Cr	0.5
7	Zn	7.3	Pb	6.0	Mo	1.3	Zn	1.7	Ni	4.2	Ni	0.3
8	Sn	7.1	Mo	6.0	Zn	1.2	Al	1.5	Ti	1.7	Pb	0.2
9	W	6.4	Ni	5.7	Al	1.1	Pb	0.8	Mo	1.2	Sn	0.0
10	Pb	4.5	W	2.7	Mn	0.5	U	0.7	Pb	0.5	Mo	0.0
11	Fe	2.4	Mn	2.0	Ti	0.3	Mn	0.4	Cr	0.3	Ti	0.0
12	Mn	2.4	Fe	0.5	Pb	0.2	V	0.3	Mn	0.2	Sb	0.0
13	Nb	2.0	Nb	0.4	Cr	0.2	Nb	0.3	V	0.2	W	0.0
14	V	0.7	U	0.1	W	0.1	Cr	0.2	Nb	0.1	Nb	0.0
15	U	0.6	V	0.1	V	0.0	Sb	0.2	Zn	0.1	V	0.0
16	Cr	0.3	Hg	0.1	Nb	0.0	W	0.1	Sb	0.0	Ag	0.0
17	Al	0.2	Al	0.0	Sb	0.0	Sn	0.1	W	0.0	U	0.0
18	Hg	0.2	Cr	0.0	Hg	0.0	Ti	0.0	Hg	0.0	Au	0.0
19	Ti	0.1	Ti	0.0	U	0.0	Hg	0.0			Hg	0.0

Under LIME 1, the following, which were specified in Table 2.11-2, were examined as possible characterization factors related directly to resource exhaustion: (1) heat value [MJ kg^{-1}]; (2) 1/*R* (normalized by antimony); (3) P/R^2 (normalized by antimony); (4) TMR-WRI (1997) [t t^{-1}] (value set based on "hidden flow" and others during this research); (5) TMR-Harada et al. (2001) [t t^{-1}]; and (6) area of land alteration [ha t^{-1}]. With regard to 19 kinds of metals, Table 2.11-3 shows the ranking of the results of multiplying domestic consumption of natural resources by the factors (2) to (6) and the ratio of the assessment result for each kind of metal to the total for the 19 kinds.

With regard to the characterization factors that focus on the amount of resources, the depletion of such kinds of resources as silver, antimony, gold, and copper was assessed as large. Meanwhile, from the viewpoint of alteration to nature due to mining, the impact on iron, copper, and other greatly consumed resources was assessed as large, and the impact on tin, gold, silver, and other metals whose consumption is relatively low also was assessed as comparatively large.

As a result of the examination, 1/*R* (normalized by antimony) was recommended as the characterization factor that takes into consideration both mineral resources and energy resources, and heat value was recommended as the characterization factor that takes into consideration only energy resources. The former is a characterization factor that focuses on mining common to minerals and fossil fuels, while the latter is a characterization factor that focuses on the aspect of fossil fuels as energy.

Indexes based on the amount of resources were adopted because importance was placed on the following: there are many cases where they were applied to cases in which LCA was carried out; many kinds of resources were considered through assessment because data directly necessary for calculation are more available than in the case of TMR and the area of land alteration (Harada et al. (2001) shows various types of estimation formulas for metal TMR in case data are not available); and the rarity of resources has been reflected. In addition, 1/*R* was adopted so that the kinds of minerals that are not produced in great quantities cannot be ignored during assessment. If P/R^2 is adopted, the characterization factor for a kind of mineral that is not much produced is great quantities becomes smaller. On the other hand, although 1/*R* may underestimate the rarity of the kinds of minerals that are produced in great quantities, such kinds of minerals were judged to be difficult to underestimate in practice because they are easy to reuse through recycling.

Under LIME 1, information on values, such as the reserves and production of main mineral resources, was gained from the Resources and Energy Handbook (Japan Society of Energy and Resources 1996), the Mineral Resources Database (Mining and Materials Processing Institute of Japan 2001), etc.

2.11.3 Damage assessment of resource consumption

(1) Basic policies for calculation of damage factors and assessment of uncertainty

Among the resources specified in 2.11.1 (1), the kinds of resources covered by the calculation of damage factors are mineral resources, fossil fuels, stone resources, and biological resources (forest resources). The areas of protection covered by the calculation (Table 2.11-4) are the impact on social assets from the viewpoint of the finite nature of resources and the impact of land use at the stage of resource gathering on the ecosystem.

Of the environmental impacts that accompany resource gathering and consumption, information on the environmental impact at the stage of resource gathering is usually supposed to be hard to provide from the result of inventory analysis under LCA in Japan. It can be said that attention has been already paid to the environmental impact of energy consumption as shown in analyses focusing on CO_2 emissions in the case of underground resources (Sagisaka et al. 1996; Moriguchi et al. 1998; Narita et al. 2001). However, the main environmental impacts due to resource gathering (see 2.11.1 (3)) cannot be covered only by this. Under LIME, the impacts of emission substances related to resource gathering, such as air pollution and water pollution, were assessed in other impact categories, such as toxic substances. Therefore, in this impact category, the impacts of the direct destruction of ground surface and the accumulation of mining waste were assessed by the use of the method to assess the damage to the ecosystem due to land use as described in Section 2.10.

Because biological resources are recyclable, if they are gathered from stock for which appropriate (sustainable) management has been carried out, the impact to resource depletion and the environmental impact of land use can be thought to be relatively small. Therefore, with regard to forest resources, the inventory side should show the status of sustainable management at gathering places and it is appropriate to determine a method for calculating the area of land use according to the division. Under this way of thinking, the scale of conservation measures, such as forestation, will be explicitly incorporated in the inventory as a negative environmental burden (that is, benefit) (see Column 2.11-4).

Figures 2.11-2 to 2.11-4 show the calculation flow of damage functions and damage factors. In addition, Tables 2.11-5 to 2.11-7 show outlines of uncertainty assessment. Among these processes, those until the calculation of the area of land use (and the location of use) can be regarded as operations for creating default (background) information on land use LCI.

Table 2.11-4: Category endpoints of resource consumption and objects of calculation of damage functions

<table>
<tr><th>Area of protection</th><th colspan="2">Category endpoint</th><th colspan="2">Object of calculation of damage functions</th></tr>
<tr><td>Human health</td><td colspan="2">(Endpoint by substances emitted at the time of resource gathering)</td><td>—</td><td>Assessor's consideration in other impact categories, such as toxic chemicals</td></tr>
<tr><td rowspan="2">Social assets</td><td>Exhaustible resources</td><td>Disappearance of resource stock</td><td>○</td><td>User cost</td></tr>
<tr><td colspan="2">(Endpoint by substances emitted at the time of resource gathering)</td><td>—</td><td>Assessor's consideration in other impact categories</td></tr>
<tr><td rowspan="4">Primary production</td><td rowspan="3">Terrestrial ecosystem</td><td>Decline in NPP during land alteration</td><td rowspan="2">○</td><td rowspan="2">Net primary production of vegetation
(Regarding the mining period as the period of maintenance of land use)</td></tr>
<tr><td>Decline in potential NPP during land use</td></tr>
<tr><td>Decline in potential NPP during recovery period after land alteration</td><td>○</td><td>Net primary production of vegetation</td></tr>
<tr><td colspan="2">(Endpoint by substances emitted at the time of resource gathering)</td><td>—</td><td>Assessor's consideration in other impact categories</td></tr>
<tr><td rowspan="2">Biodiversity</td><td>Terrestrial ecosystem</td><td>Change in composition of plant species</td><td>○</td><td>Extinction risk of vascular plants</td></tr>
<tr><td colspan="2">(Regarding the mining period as the period of maintenance of land use)</td><td>—</td><td>Assessor's consideration in other impact categories</td></tr>
</table>

With regard to primary production and biodiversity, assessment was made through the impact category of land use (for details, see Table 2.10-3).

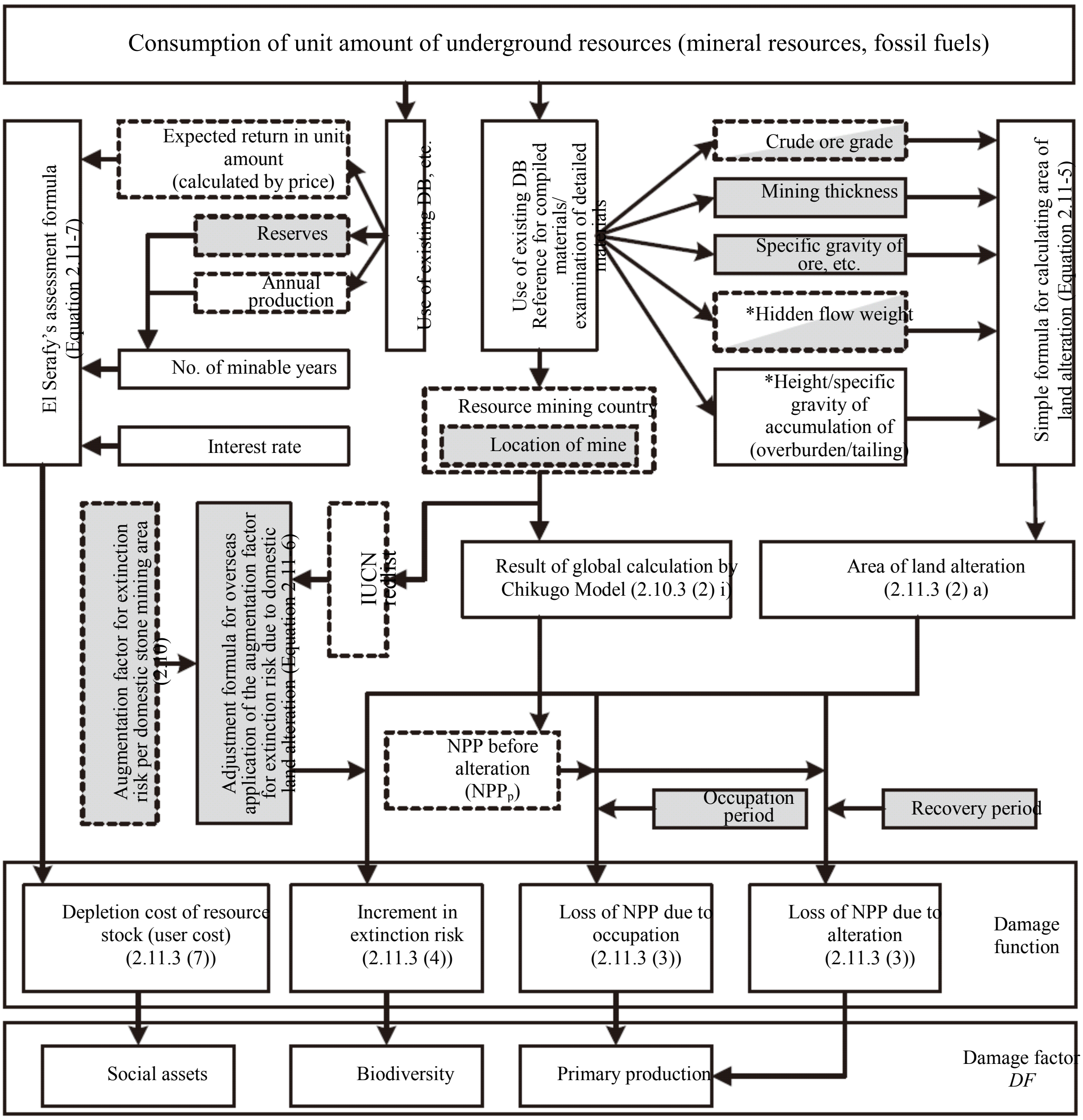


Figure 2.11-2: Calculation flow of damage factor of resource consumption (part 1: undergrounds resources – fossil fuels and mineral resources)

- The shadowed parts are factors with consideration for uncertainty of parameter. Bold dotted lines are factors with consideration for variability.
- In this figure, however, parameters that can be determined within the damage function if a mine is determined are surrounded by bold dotted lines, while parameters that are expressed by probability distribution even if a mine is determined are shadowed. Even in the latter case, however, the established probability distribution shows not estimated errors in parameters based on sample data, but data variability.
- If only a half of the inside of a frame is shadowed, treatment differs according to the kind of resource.

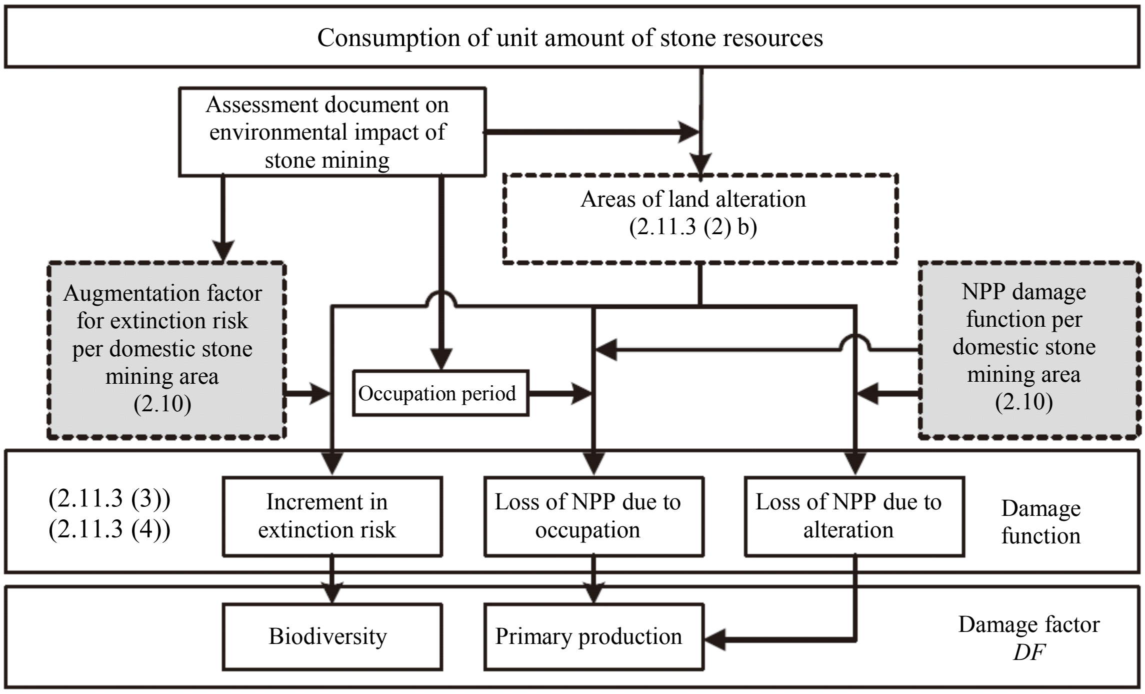


Figure 2.11-3: Calculation flow of the damage factor of resource consumption (part 2: underground resources – stone resources)

The shadowed parts are factors with consideration for uncertainty of parameter. Bold dotted lines are factors with consideration for variability.

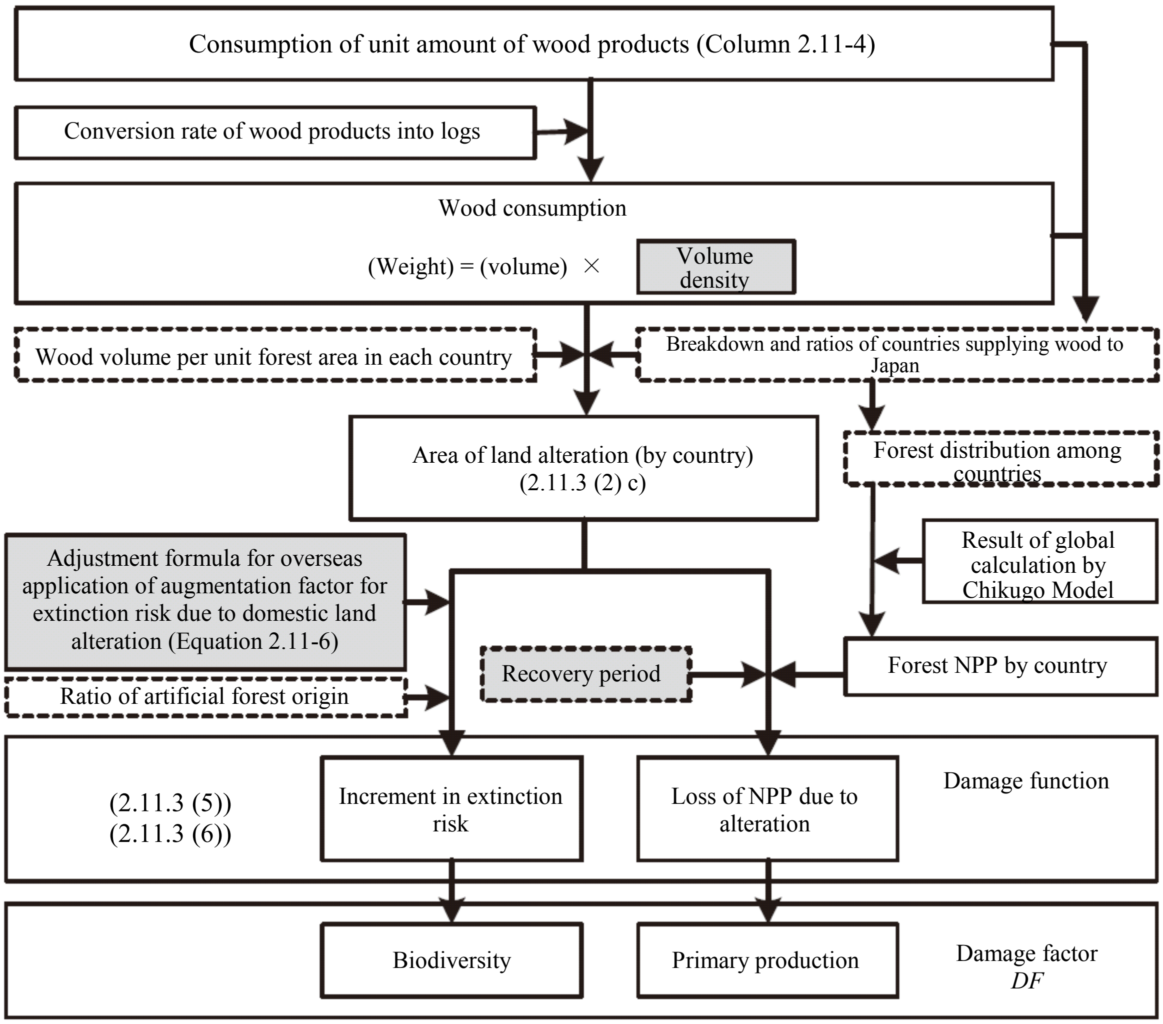


Figure 2-11-4: Calculation flow the damage factor of resource consumption (part 3: forest resources)

The shadowed parts are factors with consideration for uncertainty of parameter. Bold dotted lines are factors with consideration for variability.

Table 2.11-5: Main causes of uncertainty and policies for uncertainty assessment concerning damage functions of resource consumption (part 1: fossil fuels, metal resources)

Main possible causes of uncertainty		Policies for uncertainty assessment
Area of land use for mining of unit amount of resources (2.11. 3 (2) a)	Grade, hidden flow	Set up the grade and hidden flow (calculated values) for each mine as a variability distribution by using production volume, etc. for weighting the appearance frequency. If the values for each mine are unclear, set up a lognormal distribution, using the geometric standard deviation as the largest value of the identified metals.
	Mining thickness	Regarding iron, aluminum, and coal, set up a variability distribution from research materials. Regarding other metals, set a lognormal distribution from the geometric standard deviation of iron.
Damage function of primary production (amount of damage to primary production per land area) (2.11.3 (3))	Potential NPP (NPP_p)	If a mine has been located, refer to the NPP_p of the mesh to which the location belongs. If the location is unknown, use the spatial distribution of the NPP_p of the whole producing country as the uncertainty distribution. After that, create a variability distribution of potential NPP_p of each country or mine from Japan's import rate, etc.
	Number of years of maintenance of land use	Set up a uniform distribution from the relation between the amount of deposit and the production volume in iron ore mines.
	Recovery time of primary production	Set up the same uncertainty distribution as that of primary production damage functions of land use in 2.10.3.
Damage function of extinction risk (amount of damage to extinction risk per land area) (2.11.3 (4))	Number of endangered species in each country	Assess variability in each country, using, as the index, the number of endangered species in the IUCN Red List divided by the area of national land and using Japan's import rate as the probability of appearance.
	Application of damage factors to overseas	Assess the uncertainty of the correction rate for application of the damage factor of domestic stone mining (2.10.3) from the estimated errors in the parameters of the regression equation used for calculation of the correction rate.
Damage function of social assets (2.11.3 (7))	Price	Uncertainty distribution of the values in 2005 calculated from time-series prediction (smoothing) based on past data
	Production volume	
	Reserves	Each year's variability in the difference (ratio) between reassessed reserves in past years calculated backward from the latest estimated reserves and each year's production volume and the reserves in past years specified in statistics for past years. Regarding crude oil, however, set up a probability distribution of estimated ultimate reserves directly.

Table 2.11-6: Main causes of uncertainty and policies for uncertainty assessment concerning damage functions of resource consumption (part 2: stone resources)

Main possible causes of uncertainty	Policies for uncertainty assessment
Area of land use for mining of unit amount of resources (2.11. 3 (2) b)	Set a variability distribution based on values calculated from information specified in environmental impact assessment documents.
Damage function of primary production (amount of damage to primary production per land area) (2.11.3 (3))	Use the damage factor of land use for alteration of forests into building sites and maintenance of building sites in 2.10.3.
Damage function of extinction risk (amount of damage to extinction risk per land area) (2.11.3 (4))	Use the damage factor of land use for stone mining in 2.10.3.

Table 2.11-7: Main causes of uncertainty and policies for uncertainty assessment concerning damage functions of resource consumption (part 3: forest resources)

<table>
<tr><td colspan="2">Main possible causes of uncertainty</td><td colspan="2">Policies for uncertainty assessment</td></tr>
<tr><td rowspan="3">Area of land use for resource gathering (2.11.3 (2) c)</td><td>Volume density of wood</td><td colspan="2">Apply the value by type of tree specified in IPCC GPG-LULUCF (Penman et al. 2003) by equal probability.</td></tr>
<tr><td rowspan="2">Variability of wood volume per unit forest area</td><td colspan="2">Set up the variability of domestic wood volume (relative ratio to the wood volume in Japan specified in FAO (2002) if the area is deemed to be the relative probability of appearance) by age class (8th age class or higher) and by type of forest (natural or artificial). (Data in Japan were applied to Japan and each country and the wood volume in each country is multiplied by the relative ratio.)</td></tr>
<tr><td>Variability of wood volume in each country (FAO 2002)</td><td rowspan="6">Set up the frequency of appearance in each country from Japan's import ratio of wood (and the domestic ratio).</td></tr>
<tr><td rowspan="2">Damage function of primary production (2.11.3 (5))</td><td>Potential NPP (NPP_p)</td><td>Set up a spatial distribution of NPP_p in the forest regions in the producing country.</td></tr>
<tr><td>Recovery time for primary production</td><td>Set up a uniform distribution in each vegetation zone.</td></tr>
<tr><td rowspan="3">Damage function of extinction risk (2.11.3 (6))</td><td>Number of endangered species in each country</td><td>See Table 2.11-5.</td></tr>
<tr><td>Overseas application of damage factor</td><td>Assess the uncertainty of the correction rate when the damage factor of domestic deforestation, using estimated errors in the parameters of the regression equation used for calculation of the correction rate.</td></tr>
<tr><td>Ratio of wood produced from artificial forests</td><td>Set up a ratio of wood produced from artificial forests in each country, using the actual ratio of wood produced from artificial forests in the countries where the ratio can be grasped, or the ratio of the area of artificial forests to the total area of forests (FAO 2000) in the other countries.</td></tr>
</table>

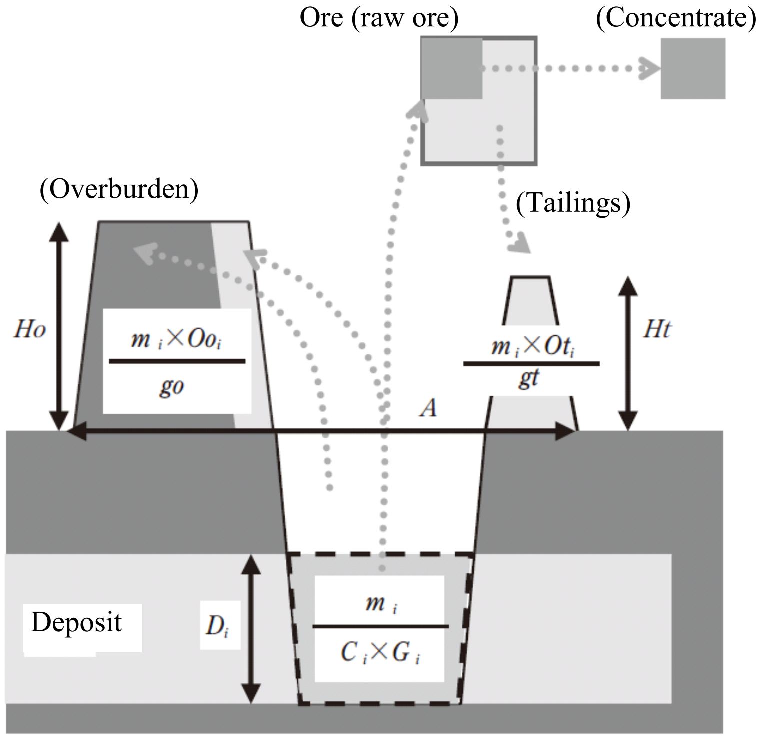
(2) Investigation of land use information

a. Calculation of the area of land use for mining of mineral resources and coal

Land use for mining of minerals and coal seems to have the following elements: (1) mining zones themselves; (2) places for accumulation of overburden produced from mining; (3) places for accumulation of tailing (waste stone) produced through ore concentration and coal preparation; and (4) zones where ore concentration or coal preparation is carried out. Their scale and degree greatly differ according to the mining method and among deposits (mines). Under LIME, element (4) was not taken into consideration.

Importance was placed on comprehensive assessment of many kinds of minerals, and a formula for rough calculation of the area of land use was introduced as shown in Equation 2.11-5. Figure 2.11-5 shows a frame format of relations among terms.

Figure 2.11-5: Frame format of land use for mining of mineral resources



$$A = m_i \times \frac{1}{C_i} \times \frac{1}{G_i} \times \frac{1}{D_i} + \left(m_i \times Oo_i \times \frac{1}{go} \times \frac{1}{Ho} + m_i \times Ot_i \times \frac{1}{gt} \times \frac{1}{Ht} \right)$$

$$\cong \overbrace{\underbrace{m_i \times \frac{1}{C_i} \times \frac{1}{G_i} \times \frac{1}{D_i}}_{b} + \underbrace{m_i \times O_i \times \frac{1}{g} \times \frac{1}{H}}_{c}}^{a} \qquad (2.11\text{-}5)$$

A: Area of land use [m^2]
m_i: Metal weight of mineral i [t]

C_i: Grade of ore of mineral i
G_i: Specific gravity of ore of mineral i
D_i: Thickness of mining of mineral i [m] (not depth but thickness of ore body)
Oo_i: Weight ratio between metal of mineral i and overburden [t/t_{metal}]
Ot_i: Weight ratio between metal of mineral i and tailings, etc. [t/t_{metal}]
O_i: Weight ratio between metal of mineral i and (overburden + tailings, etc.) (hidden flow) [t/t_{metal}]
g: Density of overburden, tailings, etc. [tm^{-3}] (go: overburden; gt: tailings, etc.)
H: Height of accumulation of overburden, tailings, etc. [m] (Ho: overburden; Ht: tailings, etc.)

The first term indicates the area of the mining site, and the (parenthesized) second term indicates the area of the site where overburden and tailings are accumulated. Although the first term is simply deducted by grade, the recovery rate of metals from ores does not reach 100% in reality. Moreover, although ores are accumulated as a horizontal layer in the frame format, the form of deposit varies in reality. In addition, the stripping ratio becomes larger as the deposit is deeper, because it is necessary to secure a stable pit slope. Therefore, it is hard to dig the ground vertically. These are causes for underestimation. Although overburden and tailings are frequently accumulated at different places and by different methods, $Ho = Ht$ and $go = gt$ are assumed for convenience of application of the hidden flow ratio available as information necessary for calculation (O_i).

All the terms are covered in the case of the open-pit mining method (the portion “a” of Equation 2.11-5). When the underground mining method is adopted, the area of the altered ground surface of the mining site itself is relatively small (although there is the possibility that a cave-in or a decline in the groundwater level may occur), and the area of accumulation of waste soil and stone seems important (only the portion “c” of Equation 2.11-5). On the other hand, when the strip mining (opencast mining) method is adopted, because stripped soil and waste stone are buried back in the mined ground behind the mining site, the area of alteration is regarded as the same as the mining zone (only the portion “b” of Equation 2.11-5). Under LIME, however, the portion “a” of Equation 2.11-5 was basically applied to all cases, because of insufficient information.

Under LIME 1, assessment was made concerning main metals (aluminum, chrome, copper, iron, lead, manganese, mercury, molybdenum, nickel, tungsten, tin, zinc, gold, silver, vanadium, antimony, titanium, and niobium).[*2] The grade was gained from Chapman et al. (1983) (same as Eco-indicator 99 (Goedkoop et al. 2000)) and the hidden flow ratio was gained from WRI (1997). It was assumed that the thickness of mining was 20 m, the density of waste soil and stone was 1.75 tm^{-3}, and the height of accumulation of waste soil and stone was 50 m (two 25-m benches were piled up). The resultant land alteration area per unit amount of resources was multiplied by the annual consumption of natural resources in Japan to calculate the annual area of land alteration. A follow-up survey (detailed survey) was carried out concerning copper, aluminum, iron and coal, which greatly contributed to land alteration, in order to review the grade, the hidden flow ratio, and other parameters. With regard to aluminum (bauxite), given that the main mining method was the opencast method,

*2 With regard to oil and natural gas (excluding tar sand and oil shale), assessment was made on the assumption that the land use area was zero, because solid matters were extracted not by removing surface and underground soil and stone but from wells (oil and gas wells), and therefore the land alteration area per amount of resources seemed small enough.

and taking into consideration the method of disposing of red mud, the land use area was reassessed.

The annual consumption of natural resources in Japan was calculated based on the total amount of imported natural resources specified by the Ecomaterials Center (website), the Mining Industry Handbook (Research Institute of Economy, Trade and Industry 2001) or the Trade Trends Database (Ministry of Economy, Trade and Industry 2001).

Under LIME 2, with regard to metal resources, a grade was set up for each mine concerning iron, zinc, lead and copper, based mainly on the mine cost database. The database was used also for estimating the hidden flow ratio.[*3] Because the grade and the hidden flow ratio were parameters related with each other, a variability distribution of grades and hidden flows was established as a variability distribution weighted by production in each mine (discrete-type joint probability function). Figure 2.11-6 shows a concrete example. With regard to iron ore, on the assumption that the thickness of ore body is the thickness of mining, a variability distribution was established from 10 cases among the research report cases (Open-air Mining Technology Research Committee 1979). In the same way, with regard to aluminum/bauxite,[*4] uranium[*5] and coal[*6] also, information on each resource was used to establish a probability distribution of these parameters. With regard to many other kinds of metal resources, information is not sufficient to establish a distribution. Because of this, among the results of adaption of lognormal distribution to the distribution of grades and hidden flows of the above-mentioned four metals, such as iron, the maximum geometric standard deviation (grade: 3.19; hidden flow ratio: 4.63) was used to set up a probability density function from lognormal deviation on the assumption that the geometric average was the same as that under LIME 1. On the assumption that mining thickness follows lognormal distribution, values under LIME 1 were given to the geometric average and the geometric standard deviation of 11 iron ore cases. With regard to the specific gravity of minerals, by reference to the Cost Estimation Handbook for the Australian Mining Industry (Noakes and Lanz 1993), values were fixed concerning iron ore,[*7] bauxite, and coal, and concerning other ores, the probability distribution was established where the value for each kind of rock was given by equal probability.

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*3 However, because impurities that seem to be produced as slag during concentration in Japan were excluded from the calculation, this is consistent with the frame format in Figure 2.11-5. This applies also to iron ores.

*4 With regard to the area of land use for aluminum and bauxite, the grade of Al_2O_3 and the thickness of bauxite were fixed at values gained from six mines and four mines, respectively (grounds for setting up a parameter under LIME 1) among the main countries from which Japan is importing them (the import ratio of aluminum ores was used as the probability of appearance for the variability distribution). With regard to other countries and mines, a uniform distribution was established based on their weighted averages and each mine's answers to a survey by IAI (1998) to assess the variability among exporting countries and mines. With regard to the area related to the disposal of red mud, a variability distribution was established from the area of land use and the volume of red mud disposed of by type of disposal method throughout the world. The amount of red mud generated per one ton of aluminum was assumed to be the same value (2.25 t/t-Al) as in the case of LIME 1.

*5 With regard to uranium, a variability distribution was established concerning the grades of the mines in Australia and Canada (the probability of appearance is the product of Japan's import rate by country and each country's production ratio).

*6 As for coal, a variability distribution was established by weighting the differences in values of parameters (hidden flow ratio, thickness of mining) among main importing country by the import rate. Although the value used by WRI for the calculation of the hidden flow in Japan was used as the hidden flow ratio, a uniform distribution was established between values in both documents concerning Australia and Canada, where information was gained through a survey under LIME 1 (IKP 2001). With regard to the thickness of mining, in Australia, Canada and US, a probability distribution was established from data on the thickness of coal beds based on surveys conducted under LIME 1; in the other countries, the thickness was assumed to be the same as that in Canada, where the width of the distribution is great.

*7 A uniform distribution was established, using the density of limonite as the minimum value and the value of hematite as the maximum value.

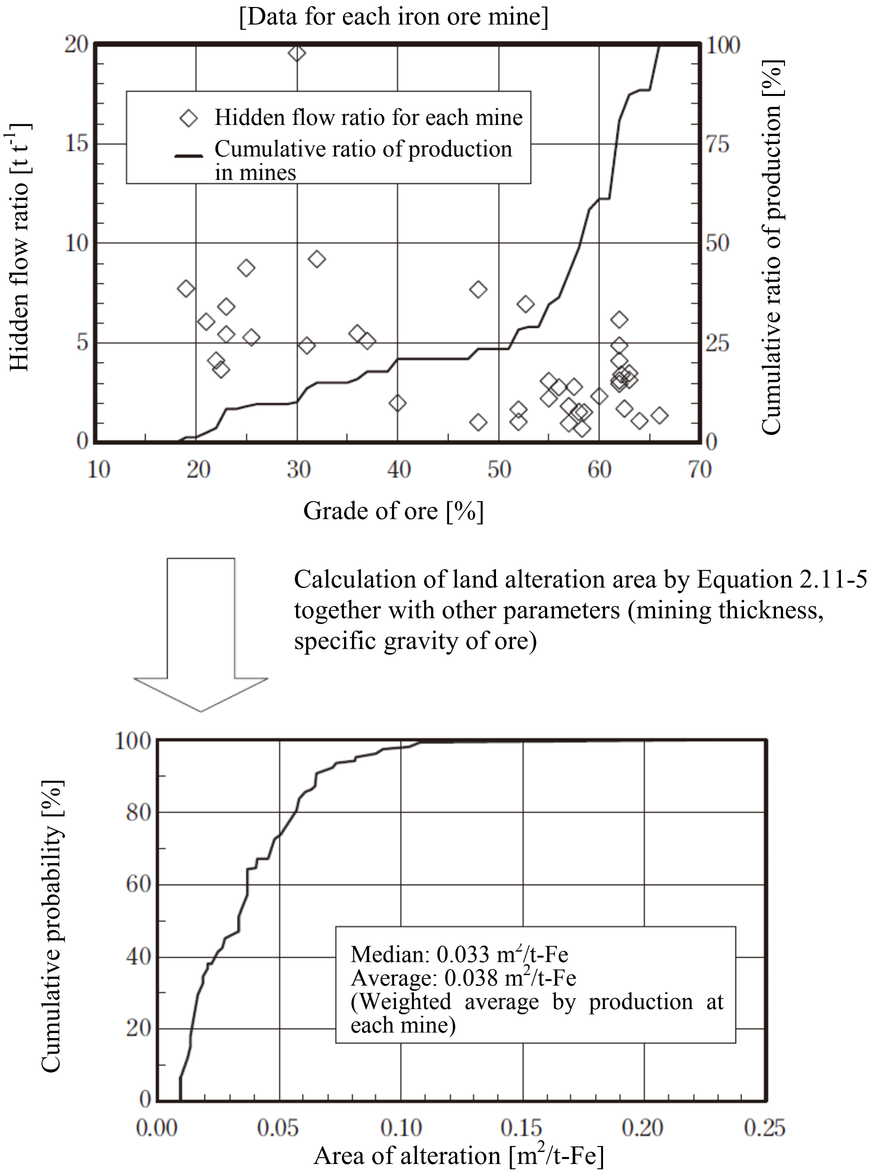

Figure 2.11-6: Example calculation of the area of alteration due to mining of mineral resources (iron)

This figure illustrates a case where the special gravity of ore is 5 and the mining thickness is about 250 m. These parameters vary during actual assessment of uncertainty of damage functions.

b. Land use for quarrying (domestic)

We arranged the environmental impact assessment documents in nine cases of quarrying (expansion of quarrying zones). In each of the cases, the quarrying period was about 20 years. Although, in some cases, the amount of overburden and waste soil and stone reaches 5 million m^3 (9 million tons), they are basically used for soil dressing for planting or reburying. When they are taken out to the outside, they are used for land development. Therefore, it was assumed that there was no impact of land use due to overburden and waste soil and stone produced by quarrying. That is, the amount of damage from land alteration directly accompanying quarrying and maintenance for 20 years was calculated. On the other hand, the area of alteration was regarded as the total area of quarrying zones. This has the possibility of overestimation.

The alteration areas divided by the total amount of quarrying were distributed between 0.013 to 0.033 m^2 t^{-1}. Under LIME 1, the representative value was 0.02 m^2 t^{-1}. Under LIME 2, we weighted this distribution by the relative ratio of the annual quarrying amount to change it into a variability distribution.

c. Land use for gathering forest resources (domestic and overseas)

The volume of wood products was converted into the volume of wood through the division of wood products by the log conversion rate. The Forestry Agency's log conversion rate for forest products was adopted. The source of the wood volume per unit forest area was the Food and Agriculture Organization of the United Nations (FAO 2002). Under LIME 2, the differences in the wood volume among countries was used for the variability distribution where the ratio for each supply country was regarded as the probability of appearance, and a probability distribution was established concerning the variability of the wood volume per unit forest area.[*8]

Under LIME 1, volume density was assessed on the assumption that 1 m^3 of wood weighs 0.5 t dm (dry matter). Under LIME 2, the table of volume density by type of tree in IPCC GPG-LULUCF (Penman et al. 2003) was applied in equal probability and used for uncertainty assessment.

The percentage distribution of supply among producing countries (import or domestic production) was set up based on the ratio between domestic and foreign materials shown in (Forestry Agency 2002a).

As described above, the process of calculating the area of land use for wood products or the volume of wood in each supply country was established and applied to the uncertainty assessment of damage functions.

(3) Primary production: damage function of mining of underground resources (mineral resources, fossil fuels, stone resources)

With regard to stone resources, as in the case of LIME 1, the damage factor calculated as in 2.10.3 was used as the damage function of primary production per area of land use.

Although the calculation procedure for mineral resources and coal is similar to that under LIME 1, a part of the procedure was detailed and uncertainty was assessed for each type of resource as follows (Figure 2.11-7):

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*8 In Japan, with regard to planned forests (forests covered by regional forest plans under Article 5 of the Forest Act and national forests covered by the forest plan in each region under Article 7-2 thereof) with an age class of 8 or more (the age of a stand is divided by a certain span (five years); the five years following planting are the age class of 1; the 6th to 10th years are the age class of 2), accumulation for unit area was calculated by type of forest (artificial or natural) and age class, and the ratio with the wood volume per unit forest area shown in FAO (2002) was calculated. On the assumption that the area by type of forest (artificial or natural) and age class was the relative probability of appearance, the distribution of the ratio was applied to Japan and each foreign country as variability distribution of wood volume per unit deforestation area. However, the area by age class for natural forests only was used as the damage function of biodiversity.

Country	Mine	NPPp [t ha^{-1} yr^{-1}]	Amount of damage per unit area [t ha^{-1}]	
			Maintenance	Alteration
Australia	Mount Newman	0	0	0
Australia	Hamersley	0.2	10	15
Australia	Savage River	12.8	640	960
Brazil	Carajas	23.6	1,180	1,770
Brazil	Capanema	25.0	1,250	1,875

Parameters related to iron ore	
Grade	53%
Specific gravity of ore	4.44
Hidden flow ratio	3.16

(Equation 2.11-5)

(Figure 2.11-5)

Area of land use [m^2/t-Fe]	0.038

Country	Import ratio (1999) [%]	Average amount of damage per unit area in primary production [t ha^{-1}]		Extinction risk	
		Maintenance	Alteration	α	Amount of damage per unit area [EINES ha^{-1}]
Australia	53	206	309	0.169	4.36×10^{-7}
India	13	1,000	1,500	2.55	1.44×10^{-6}
Brazil	21	1,123	1,685	1.53	1.01×10^{-6}
Other	13	—	—	—	—
Weighted average by import ratio		428	643	—	7.26×10^{-7}

DF_{NPP}(iron) = (428+643) × ($10^3\times10^{-4}$) × (0.038×10^{-3}) = 4.07×10^{-3} (kg-NPP/kg-Fe)

DF_{EINES} (iron) = (7.26×10^{-7}) × 10^{-4} × (0.038×10^{-3}) = 2.76×10^{-15} (EINES/kg-Fe)

Figure 2.11-7: Example calculation of damage functions of mineral resources (iron)

- To illustrate the calculation process, the figure shows the result of calculation by setting up a point estimate for each parameter. Therefore, this is inconsistent with the list of factors (result of uncertainty assessment).
- The value of the hidden flow of iron ore was calculated by excluding the blast furnace slag produced domestically. The import ratio of each country is from the Mining Industry Handbook (Research Institute of Economy, Trade and Industry 2001).

Table 2.11-8: Example calculation of the damage function of forest resources (wood)

Country	Wood volume of forest [m^3 ha^{-1}]		Alteration area per wood weight [ha t^{-1}]		Wood supply ratio (2000) [%]
	(1)	(2)	(1)	(2)	
US	176	127	0.0114	0.0157	15.9
Canada	155	112	0.0129	0.0178	14.5
Japan	188	135	0.0106	0.0148	18.9
Other	130	93	0.0154	0.0214	13.6

- Representative value of volume/weight conversion rate [t dm m^{-3}] of wood: 0.5

Country	[(1) Primary production]				[(2) Extinction risk]		
	Average for forest NPPp [t ha^{-1} yr^{-1}]	Recovery period [yr]	Alteration damage amount per area [t ha^{-1}]	Damage function by country	Growth density factor for endangered species	Alteration damage amount per area [EINES ha^{-1}]	Damage factor by country
US	8.9	35	156	1.77	0.632	8.73×10^{-7}	1.37×10^{-11}
Canada	3.1	82	126	1.62	0.004	3.29×10^{-7}	5.88×10^{-12}
Japan	11.4	25	143	1.52	1.000	1.19×10^{-6}	1.76×10^{-11}
Other	8.0	30	120	1.85	*	5.79×10^{-6}	*
Average damage factor (unknown country of origin)				1.81			1.03×10^{-10}

- To illustrate the calculation process, the figure shows the result of calculation by setting up a point estimate for each parameter. Therefore, this is inconsistent with the list of factors (result of uncertainty assessment).
- In this table, the unit of damage function is kg-NPP/kg-wood (average for natural and artificial forests) for primary production and EINES/kg-wood (natural forests) for the extinction risk. The value of damage factor is the average for natural and artificial forests also in the case of extinction risk.
- Land alteration area is calculated for both natural and artificial forests in the case of primary production (1) and for natural forests in the case of the extinction risk (2).
- Wood supply ratio is from the Forestry Agency's "Annual Report on Forest and Forestry in Japan" (Forestry Agency 2002a). The wood volume in forests was calculated by multiplying the wood volume in forests (m^3 ha^{-1}) in "State of the World's Forests 2001" FAO (2002) by 0.93, which was calculated from the value in Japan and the ratio between the accumulation and the area of forests with an age class of 8 years or more (Forestry Agency 2002b).
- The wood volume in forests in the countries that falls under "Other" is the world average, and the alteration damage amount per area in the countries is the average for other supply countries.

First, to assess the damage of land use for mining of resources, the global potential net primary production (NPP) was estimated by applying the Chikugo model (Uchijima et al. 1985; Seino et al. 1985) as in Japan (see 2.10.3). The values of temperature and rainfall necessary for calculation were the averages between 1981 and 1990 (IPCC 2002). The annual net radiation in the model was calculated by applying the relational expression between temperature and annual net radiation in Seino et al. (1992).

With regard to some iron and copper mines whose locations (latitudes and longitudes) were surveyed during LIME 1, NPP_p at the locations were set up based on the results of the survey (in a form with no uncertainty). On the other hand, with regard to mines whose locations were not identified and mines for which no location information was found other than the countries to which they belonged, the probability distribution of NPP_p of each of the exporting countries (frequency distribution of NPP_p calculated for each mesh in comparison with the whole world) was set up. A variability distribution was established as the assemblage of them, and Japan's import ratio by type of resource (with regard to a mine in a country, the ratio was multiplied by the ratio of the production in the mine to the total production of the country; therefore, no consideration was given to the mine's export ratio to Japan) was used as the probability of appearance for each of them.

With regard to the number of years for recovery of primary production, because the degree of artificial alteration, such as urban land use and mineral resource mining, is large for the uncertainty assessment of land use (2.10.3 (2) f), a uniform distribution of recovery periods lasting 50 to 250 years was established and applied to cases where soil would be lost for a while. If a place for mining mineral resources is restored after mining, it seems appropriate to set up a relatively small number of years for recovery. Such cases were reflected somewhat in the above-mentioned distribution of a wide range of recovery periods.

Under LIME, the period of mining in a mine is the number of years of land use used for damage assessment. Under LIME 2, the relation between iron reserves (including not only confirmed reserves but also estimated reserves) and production volume was clarified based on materials arranged about iron ore mines to which the surface mining method was adopted (Open-air Mining Technology Research Committee 1979), and the number of minable years for each mine was calculated by dividing reserves (estimated at a certain point of time) by production volume (in a certain year). After that, on the assumption that the probability distribution of mining periods ranged from 5.7 years to 223 years and that the maximum value was 45.7 years, which is the number of minable years that corresponded to the inclination of the regression equation as a result of regression analysis of reserves to production volume (under LIME ver. 1, the parameter was 50 years, almost the same value), a triangular distribution was set up for all underground resources.

(4) Biodiversity: damage function of mining of underground resources (mineral resources, fossil fuels, stone resources)

With regard to stone resources, the damage factor of quarrying calculated in 2.10.3 (4) b was used as the damage function of biodiversity per land use area.

The following three causes were taken into consideration during the uncertainty assessment of the damage function (Figure 2.11-7) of biodiversity (extinction risk) due to mineral resources and coal: the variability of the number density of endangered species in each country according to Japan's import ratio; the uncertainty of correction rate; and the uncertainty of the increment in the extinction risk per quarrying area. Details are as follows:

Under LIME 2, consideration was given to how to weight the amount of damage per unit area according to the situation of biodiversity in the exporting countries to Japan, and the result was incorporated in the calculation as the correction rate (random variable that has uncertainty) for the amount of damage per area of domestic stone mining (parameter used for LIME 1). Concretely, with regard to the domestic cases covered by the environmental impact assessment (EIA) during LIME 1, which included the calculation of an increment in the extinction risk, a model where the number of endangered species and the increment in the extinction risk were used as the explanatory variable and the objective variable, respectively, was created through regression analysis of the value of increment in the extinction risk and the number of endangered vascular plant species,[*9] which was reported to exist in each of the domestic secondary meshes (about 10 km) where the cases were located. In the following equation, x is the number of endangered species in a mesh, and 4.39 is the average value for x in all the assessment cases. SE in parentheses is the standard deviation of the regression parameter. The parameter was deemed to follow a normal distribution and was used as the standard deviation for the uncertainty assessment of the damage function.

$$\mathrm{UAR}(x) = 6.57\mathrm{E}{-9}\ (\mathrm{SE}\ 2.52\mathrm{E}{-9}) \times (x - 4.39) + 3.74\mathrm{E}{-8}\ (\mathrm{SE}\ 9.48\mathrm{E}{-9}) \quad (2.11\text{-}6)$$

The average of x was 1.50 concerning the assessed stone mining. Therefore, the correction rate of the increased extinction risk (UAR) to be applied to resource gathering if the number of endangered species is α times as large was defined as UAR (1.50α) ÷ UAR (1.50) (Figure 2.11-8). Although this relation was calculated for Japan only, it was audaciously assumed that this was applicable to foreign countries, and the value of α was replaced by the ratio between Japan and resource exporting countries concerning the number of endangered species divided by the national land area specified in the IUCN Red List (2002).

*9 The number of endangered species whose locations have been published is limited. Because the growth of endangered species has not been confirmed or has been unknown in Type-0 meshes, assessment was carried out concerning Type-1 and higher meshes.

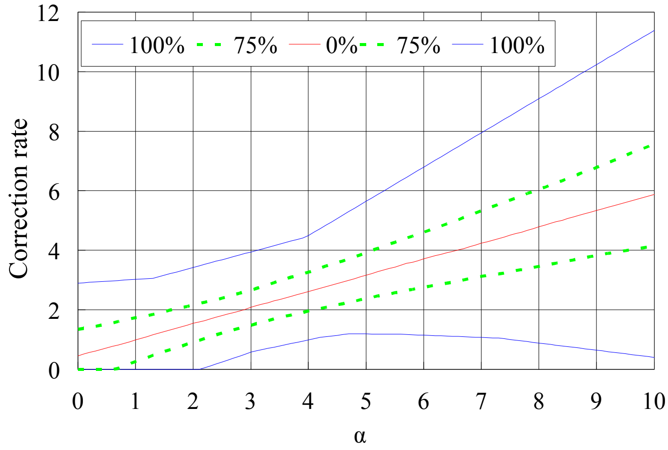

Figure 2.11-8: Correction rate for an increment in the extinction risk corresponding to the rate of increase in the number of endangered species

(5) Primary production: damage function of forest resource gathering

With regard to the unit amount of wood products, the area of land use by type of wood product and by country as described in (2) c was multiplied by the amount of damage to primary production per unit due to deforestation calculated from NPP shown in 2.11.3 (4) and the recovery time of productivity fixed in Table 2.11-9 in order to calculate the amount of damage by type of wood product and by country (Table 2.11-8).

With regard to NPP, the variability of forest NPP in each country was set up by the use of data on the potential NPP of the grids included in the forest category in each country. With regard to recovery time, a uniform distribution was adopted, due to lack of information. Maximum and minimum limits were basically fixed by the use of the recovery periods for the neighboring climate zones (Table 2.11-9).

Table 2.11-9: Establishment of a probability distribution of recovery time

	Tropical	Subtropical	Temperate	Boreal
Range of distribution (years)	1-19	10-30	20-40	30-170
Recovery time (years)	10	20	30	100

(6) Biodiversity: damage function of forest resource gathering

The calculation flow is the same as that for the damage function of primary production in (5). With regard to the damage function of wood, on the assumption that it was impossible to distinguish whether or not wood entered in inventory was produced from artificial forests, Monte Carlo calculation was tried according to the ratio of wood from artificial forests fixed for each country. When it was assumed that wood was produced from planted trees, the amount of damage was fixed at 0. When it was assumed that wood was not produced from artificial forests, the amount of damage was calculated as follows:

By the method specified in 2.10.3 (3) h, the damage factor per area of domestic deforestation was calculated by dividing the estimated increase in the extinction risk due to domestic deforestation (result of distribution of the normalization value; no probability density distribution could be established) into that per area of deforestation, regarding the deforestation as that of natural forests. The result was applied to Equation 2.11-6 to set up a correction rate for uncertainty and overseas, which was then used for the calculation of the damage function of the endangered risk.

(7) Social Assets: damage function of consumption of mineral resources and fossil fuels

a. Concept of damage function

The Cabinet Office (former Economic Planning Agency) has promoted research and development about the environment and economy integration account. During the course of research and development, it has estimated the imputed environmental cost (amount of depletion of environmental assets) basically by the maintenance cost assessment method (whereby indirect assessment is made by the use of the estimated cost necessary for maintaining actual qualitative and quantitative environmental changes).

With regard to the depletion of underground resources, the amount of depletion calculated by the user cost method by El Serafy (1989) has been estimated as the imputed environmental cost for the current term. El Serafy's user cost is the amount of money that becomes necessary when a part of revenues from gathering of underground resources in every term is invested in other assets so that the same income (permanent income) can be gained even after the resource is depleted. The cost is the difference between profits in every term and the permanent income (Figure 2.11-9). Concretely, the user cost is calculated by Equation 2.11-7 (El Serafy 1989).

$$\text{User Cost} = R - X = \{ 1/(1+r)^n \} \cdot R \tag{2.11-7}$$

In this equation, R is revenue, X is permanent income, n is the number of years of mining, and r is interest rate (for example, 3%).

The above-mentioned environment and economy integration account (Economic Planning Agency 1998) was calculated by the use of production volume multiplied by price as R (the mining cost was assumed to be 0) and minable reserves divided by production volume as n. The following are points that require attention when values are actually calculated: (1) exponential changes in estimated values due to changes in production volume; (2) great changes in estimate results due to changes in interest rate; and (3) the user cost estimated for each mine and the user cost estimated from the total amount of resources in the whole world – that is, calculated values and their meanings differ between the case where user cost is calculated for each mine, whose durations differ from each other, and the case where user cost is calculated from the total amount of resources in the whole world (Cabinet Office 2001).

Ariyoshi et al. (1996) emphasized theoretical important points concerning this user cost. For example, (1) although a certain amount of income is guaranteed for the future, this does not mean the sustainability of the resources (from the outset, the object of assessment is exhaustible resources); and (2) it is implicitly assumed that interest will be gained from invested assets even after the depletion of the resources.

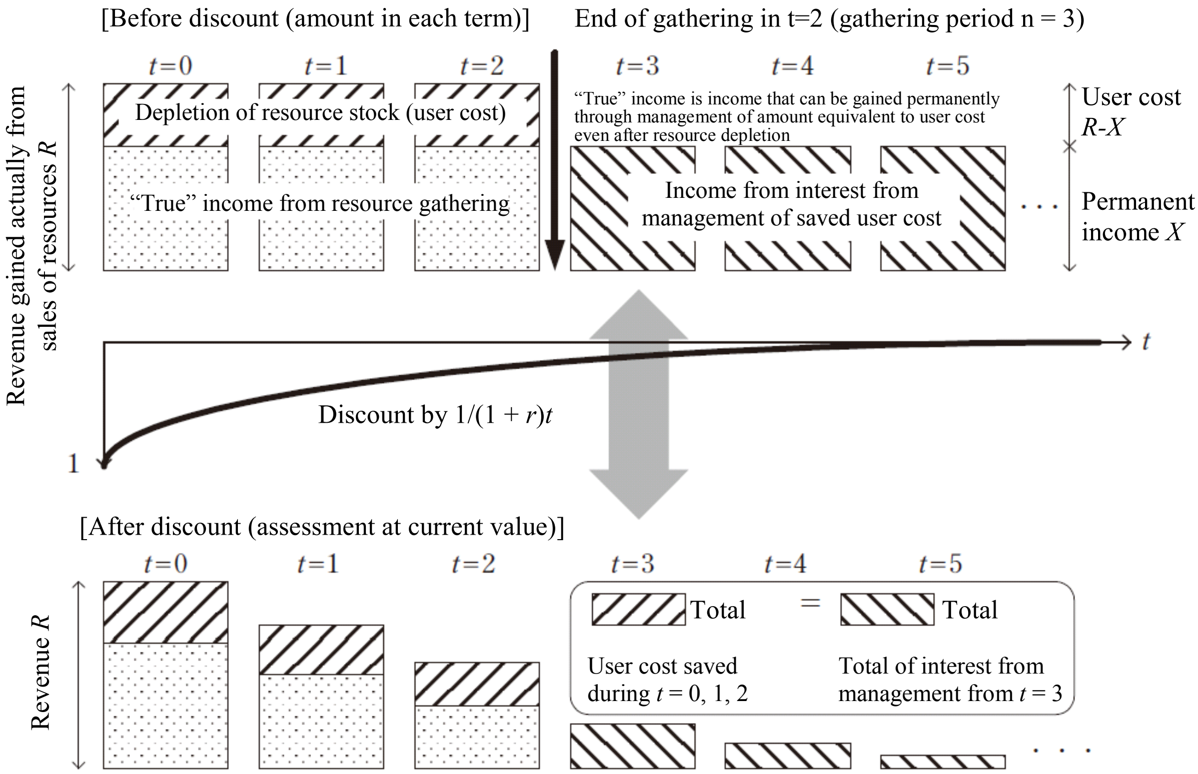

Figure 2.11-9: Concept of user cost by El Serafy

- Mining begins at $t = 0$ and ends at $t = 2$. After that, no revenue can be gained from sales of mined resources.
- To continue to gain revenues after the end of the mining, it is necessary to shift a certain amount of money ("depreciation" of resources = user cost) from revenues to the management of other assets.
- The "true" income is the amount of the permanent income series achieved through the management of assets (interest). The user cost is calculated as the level where the sales revenue deducted by the user cost becomes equal to the interest income.

Because El Serafy's user cost serves as "depreciation" of resource stock from the viewpoint of a permanent income series that intends to weaken sustainability (see Column 2.11-3), it should be deducted afterwards from a part of the value added produced by resource gathering (El Serafy 1997). Therefore, when interpreting the results of damage assessment, it is necessary to pay attention to the differences between damage assessment by user cost and that by other damage functions.

b. Parameters used for calculation of damage functions

Under LIME 1, with regard to minerals and fossil fuels, interest rates of 3% and 5% were used for the calculation of the user cost (annual depletion cost of exhaustible resources in the whole world) and the user cost per unit weight [$ kg^{-1}]. As for the parameters used for the calculation, because price and other conditions may change greatly during a short time, temporal changes seem to influence the damage factor of this impact category greatly.

Under LIME 2, it was decided that a damage factor should be provided for 2005, the last year of the project period. Values calculated from time-series prediction (smoothing) based on past data were used as the parameters for 2005 so that expected values and variability based on changes so far could be reflected in the assessment. It can be thought not only that reserves will simply decrease due to mining but also that there will be an addition (increase) as a result of exploration and other changes as a result of technical and economical causes. Therefore, with regard to reserves, it was decided, for example, that past years' reserves should be calculated backwards from the latest estimate of reserves every year, and each year's production volume and the difference (ratio) of the current year's reserves in past years' statistics should be calculated every year. With regard to the latest reserves also, because such changes were considered to occur, it was decided that uncertainty should be assessed for convenience and that the latest reserves deducted by the production volume estimated for each future year should be used as reserves in that year. With regard to crude oil, however, because the ratio of reserves to the normalization value is great, the already estimated ultimate reserves were used.[*10] Although the ultimate reserves of oil differ according to estimation (Energy Supply-Demand Subcommittee of Advisory Committee for Natural Resources and Energy 2005), LIME 2 referred to the US Geological Survey's latest estimate in 2000 (USGS 2000), also referring to description by OECD/IEA (2004). Because this estimate was made as a probability distribution and shows the results of interval estimation, a probability distribution of ultimate reserves was established based on this.

As basic data for setting up parameters, the "Mineral Resources Database 2001" (compiled by the Resources Economy Committee of the Mining and Materials Processing Institute of Japan) was referred to concerning metal resources, and changes over time were arranged for about 20 years from 1980 in principle. In addition, whenever needed, USGS's "Mineral Commodity Summaries" (each year's edition) was referred to concerning the metals for which the Database did not provide sufficient information, and "The Red Book Perspective" (OECD/NEA 2006) was referred to concerning uranium. With regard to fossil fuels, "BP Statistical Review of World Energy" (BP 2005) provided by BP (former British Petroleum) was referred to in the same way (excluding the above-mentioned ultimate reserves of crude oil). To convert dollars into yen, 110.75 yen/$ was used as the exchange rate of 2005.

(8) Social assets: damage factor of forest resource consumption

Biological resources (forests) not only serve as places of wood production but also have various functions that provide many kinds of environmental services, including socioeconomic benefits (which are not contained in the market price of wood). Therefore, during damage assessment, it is necessary to consider not only depletion (simply, deforestation whose speed exceeds the speed of regeneration) but also the loss of such multiple functions. However, methodology for assessing the depletion of biological resources (forests) as resource stock and the environmental services provided by forests during LCIA has not been discussed fully and depends on the development of research in the future.

In Japan, forest functions have been quantitatively assessed by the Forest Agency's assessment of the Japanese forests' function to enhance the public interest, the Science Council of Japan's review, and the Mitsubishi Research Institute's assessment based on the review.

[*10] The reserves of crude oil increased to twice as much as 20 years ago. If the production volume accumulated during the period is added, it increased three times. However, a sharp increase in the reserves in all the OPEC member countries during 1985-1990 was due to the negotiations about production allocation at that time and was said to have almost no relation with actual discovery of new reserves (OECD/IEA 2005).

The Forest Agency (2000) divided forests' functions into the following: (1) cultivation of water sources; (2) prevention of mountain disasters; (3) conservation of the living environment; (4) health culture; and (5) production of wood, etc. The Forest Agency subdivided them and assessed some of the subdivided functions by the replacement cost method.

On the other hand, the Science Council of Japan divided forests' multiple functions into the following in its report (Science of Council of Japan 2001): (1) conservation of biodiversity; (2) conservation of the global environment; (3) prevention of sediment disasters and soil conservation; (4) cultivation of water sources; (5) creation of comfortable environments; (6) health and recreation; (7) culture; and (8) matter production. The Council showed whether or not quantitative assessment is possible concerning each of the eight divisions. Based on the results, the Mitsubishi Research Institute assessed some of the functions by the replacement cost method.

Famous assessment of biological functions on a global scale is Constanza et al. (1997), who monetarily assessed 17 biological functions of 16 biomes (including two forest biomes: tropical forests and temperate/boreal forests). The assessed value (per area) of the temperate forests is far smaller than the Forest Agency's.

Under LIME 1, based on the results of the assessment of service values by Costanza et al. (1997), and paying attention to the possibility of overlap with the other areas of protection, we tried to derive the damage function per unit amount of consumed wood by applying the forest structure in each country, the number of years for recovery fixed in 2.11.5 (3) b, and the interest rate fixed in 2.11.3 (7). After that, to assess the depletion of forest stock, we tried to calculate the amount of growth of forests and the amount of deforestation on a world scale. However, the damage function could not be calculated, due to insufficient grasp of the amount of deforestation.

(9) Damage factor of resource consumption

In the impact category of resource consumption, because there is only one kind of endpoint for the damage factor for biodiversity and social assets, the representative value of the damage function is used as the damage factor as it is. The damage index for primary production is the total of the damage factors for land alteration and maintenance. The following are explanations about the result of the calculation of the damage factor for each area of protection:

a. Damage factor for primary production

With regard to some kinds of resources, statistical values (Table 2.11-10) and cumulative frequency distributions (Figure 2.11-10) were presented herein as examples. With regard to the damage factor for stone that can be mined only in Japan, the coefficient of variation became relatively small.

Compared with LIME 1 (Figure 2.11-11), although differences in size among resources have been maintained generally, there are many kinds of resources about which the median of the damage factor under LIME 2 was calculated to be lower than that under LIME 1.

Although, as shown in Table 2.11-11, causes for the uncertainty of the damage factor differ among kinds of resources, causes for the uncertainty were extracted from both the process of estimating the area of land alteration due to resource gathering and the process of estimating the amount of damage per land area. Many of the causes are variables that express geographical variability.

The damage factor for wood is larger than that for copper, for example. This is partly because of difference in the density of resources. If 1 m^3 of rock is gathered from rock with a thickness of 50 m, the altered "area" is only 0.02 m^2/m^3. On the other hand, if the accumulated volume of wood is about 100 m^3/ha, the area of forest necessary for gathering 1 m^3 of wood is 100 m^2/m^3. The latter is 5,000 times as large as the former. If difference in specific gravity is taken into consideration, the difference between the two in area per weight widens severalfold. On the other hand, the two seem to differ from each other in the state of the ecosystem after resource gathering. If no activities for restoring nature are taken after rock mining, surface soil will be lost and it will be impossible to expect primary production. However, forest gathering can be thought to be a land altering act more moderate than rock mining. Therefore, damage assessment requires appropriate differentiation of damage amount per area of land use. Differences between the two that have been taken into consideration under the current LIME are limited to the following: although the maintenance of land use (number of minable years) is included in damage assessment in the case of underground resources, only the act of alteration is dealt with in the case of deforestation; and the time for recovery of primary production volume after gathering is somewhat shorter in the case of deforestation. As a result, the amount of damage to primary production per unit land area in the case of underground resources is only about ten times as large as in the case of wood. In addition, attention should be paid to the fact that the damage factor for wood presented herein is applicable also to a gathering method whereby a forest becomes bare land after total deforestation.

Table 2.11-10: Example of statistical values of primary production damage factors of resource gathering

[kg-NPP/kg]	Rock	Iron	Lead	Copper	Wood
Number of trials	50,000	50,000	50,000	50,000	50,000
Average	2.11E-03	6.16E-03	2.02E-01	8.74E-01	2.41E+00
Median	1.82E-03	1.43E-03	5.17E-02	3.55E-01	1.61E+00
Standard deviation	1.19E-03	9.97E-03	6.93E-01	1.48E+00	3.25E+00
Dispersion	1.42E-06	9.94E-05	4.80E-01	2.21E+00	1.05E+01
Skewness	1.5	3.1	19.8	5.1	6.9
Kurtosis	5.6	19.4	808.6	57.3	94.8
Coefficient of variation	0.6	1.6	3.4	1.7	1.3
10% value	9.47E-04	0.00E+00	6.26E-04	0.00E+00	3.44E-01
90% value	3.81E-03	1.85E-02	4.37E-01	2.39E+00	4.84E+00
Average standard error	7.27E-03	3.44E-03	4.43E-05	5.01E-06	1.45E-02

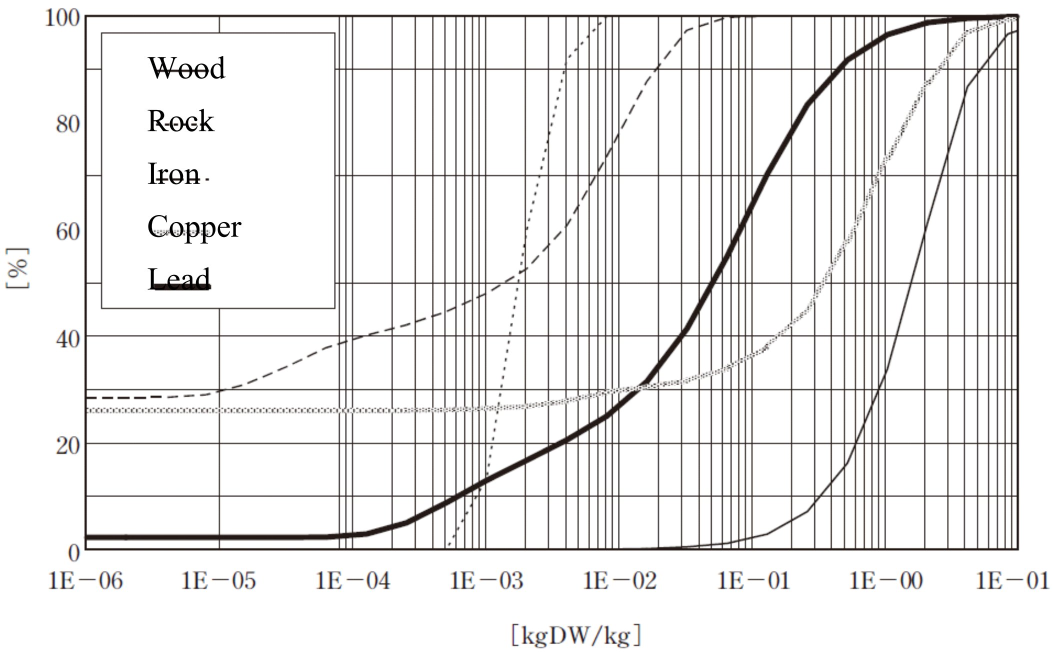

Figure 2.11-10: Example of prediction result of probability density distribution of primary production damage factors of resource gathering

The cumulative probability does not become 0% even in the case of 1E-6kgDW/kg, because a trial where the potential NPP at the point of mining was assessed as 0tDW/ha (therefore, the damage factor is zero) is reflected.

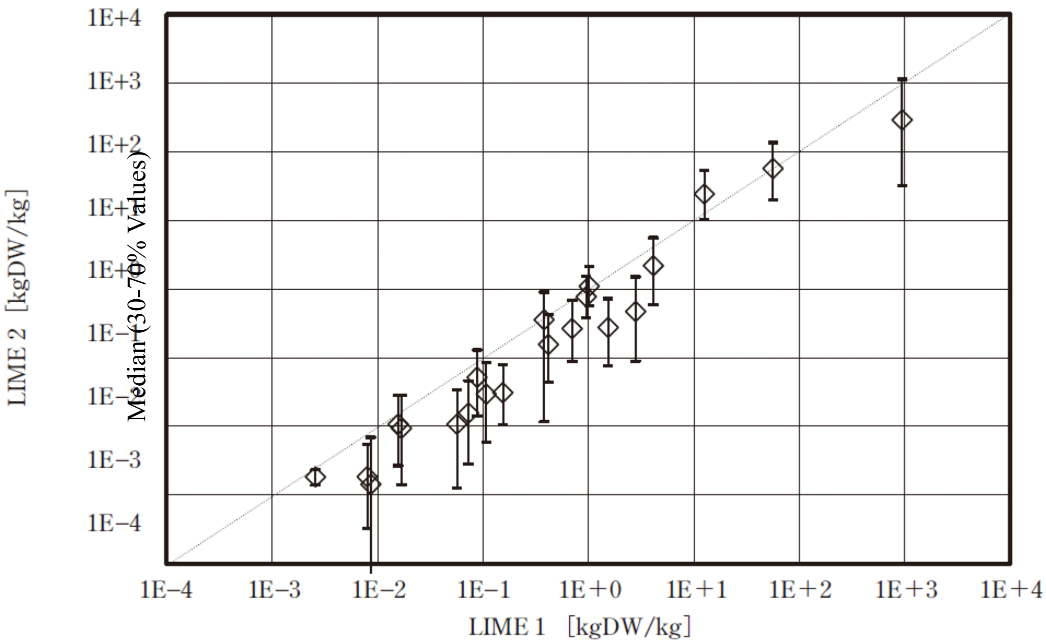

Figure 2.11-11: Comparison between LIME 1 and LIME 2 in primary production damage factor of underground resources

Table 2.11-11: Example of rank correlation of primary production damage factors of underground resources

	Rock		Iron		Lead		Copper	
#1	(2) Recovery time for primary production	0.64	(2) Variability of primary production according to differences among mines and exporting countries	0.46	(1) Variability of grade and hidden flow	0.33	(2) Spatial distribution of potential NPP (Chile)	0.29
#2	(1) Variability of land alteration area ratio at each mining point	0.54	(1) Variability of grade and hidden flow	0.20	(2) Spatial distribution of potential NPP (Australia)	0.32	(1) Variability of grade and hidden flow	0.25
#3	(2) Damage factor for land use maintenance at building sites (substitute for resource gathering)	0.33	(2) Spatial distribution of potential NPP (Australia)	0.15	(2) Variability of primary production according to differences among mines and exporting countries	0.29	(2) Variability of primary production according to differences among mines and exporting countries	0.24
#4			(2) Mining period	0.09	(1) Mining thickness	-0.29	(1) Mining thickness	-0.14
#5			(2) Recovery time for primary production	0.06	(2) Spatial distribution of potential NPP (US)	0.17	(2) Mining period	0.11
#6			(1) Mining thickness	-0.04	(2) Mining period	0.12	(2) Recovery time for primary production	0.09
#7			(2) Spatial distribution of potential NPP (India)	0.03	(2) Recovery time for primary production	0.09	(2) Spatial distribution of potential NPP (Canada)	0.03

- The top 7 causes were extracted.
- 1) indicates a cause for uncertainty concerning the estimation of the area of land use for resource gathering.
- 2) indicates a cause for uncertainty concerning the estimation of the amount of damage per area of land use. However, for convenience of implementing damage functions, the rank correlation of variability of primary production according to difference among mines and exporting countries is underestimated.

Table 2.11-12: Example of statistical values of damage factors for biodiversity

[EINES/kg]	Rock	Iron	Lead	Copper	Wood
Number of trials	50,000	50,000	50,000	50,000	50,000
Average	8.50E-14	2.08E-13	9.41E-12	6.31E-11	1.42E-10
Median	1.35E-15	1.91E-15	3.76E-14	6.75E-13	1.35E-11
Standard deviation	3.10E-13	1.06E-12	9.04E-11	3.27E-10	1.03E-09
Dispersion	9.58E-26	1.13E-24	8.18E-21	1.07E-19	1.05E-18
Skewness	5.4	10.1	27.5	11.8	125.11
Kurtosis	43.8	169.2	1,067.9	237.8	21,734.4
Coefficient of variation	3.6	5.1	9.6	5.2	7.2
10% value	6.18E-17	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90% value	5.16E-14	8.55E-14	2.70E-12	3.46E-11	2.38E-10
Average standard error	1.38E-15	4.74E-15	4.04E-13	1.46E-12	3.16E-12

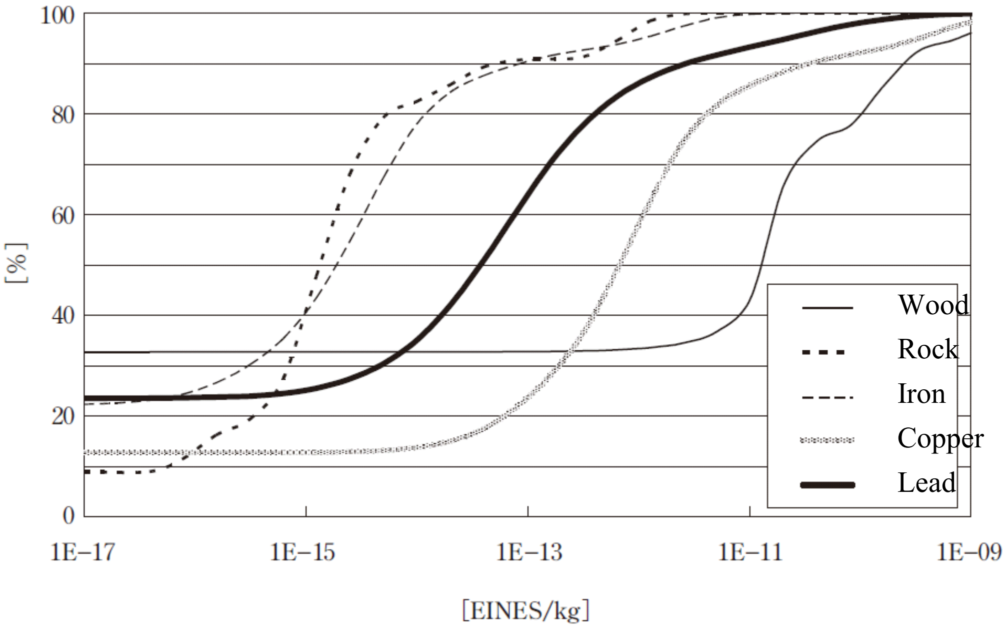

Figure 2.11-12: Example of prediction result of cumulative frequency of damage factor for biodiversity

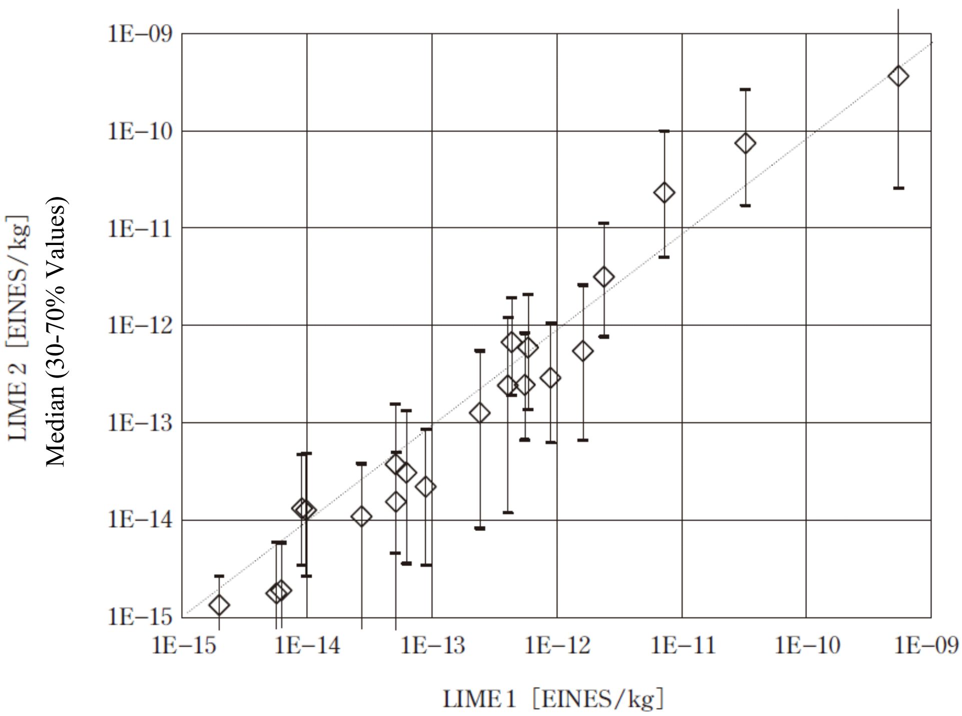

Figure 2.11-13: Comparison between LIME 1 and LIME 2 in biodiversity damage factor of underground resources

Table 2.11-13: Example of rank correlation of biodiversity damage factors of underground resources

	Rock		Iron		Lead		Copper	
#1	(3) Variability of UAR of rock mining cases	0.93	(3) Variability of UAR of rock mining cases	0.64	(3) Variability of UAR of rock mining cases	0.58	(3) Variability of UAR of rock mining cases	0.77
#2	(1) Variability of land alteration area rate by point of mining	0.17	(2) Correction rate regression equation (intercept)	0.31	(2) Correction rate regression equation (intercept)	0.32	(1) Variability of grade and hidden flow	0.23
#3	(3) Tsim (Calanthe discolor)	-0.05	(2) Correction rate regression equation (slope)	-0.29	(2) Correction rate regression equation (slope)	-0.31	(2) Correction rate regression equation (intercept)	0.17
#4	(3) N_4 (Calanthe discolor)	-0.04	(2) Variability of primary production according to difference among mines / exporting countries	0.23	(1) Variability of grade and hidden flow	0.18	(1) Mining thickness	-0.13
#5	(3) N_4 (Calanthe discolor)	-0.04	(1) Variability of grade and hidden flow	0.19	(2) Variability of primary production according to difference among mines / exporting countries	0.18	(2) Correction rate regression equation (slope)	-0.09
#6	(3)Tsim (Cephalanthera falcate)	-0.04	(1) Mining thickness	-0.04	(1) Mining thickness	-0.15	(2) Variability of primary production according to difference among mines / exporting countries	-0.04
#7	(3) Population of Calanthe discolor in a rock mining case	0.04	(3) Tsim (Calanthe discolor)	-0.02	(3) N_4 (Calanthe discolor)	-0.02	(3) Tsim (Calanthe discolor)	-0.03

- 1) indicates a cause for uncertainty concerning the estimation of the area of land alteration due to resource mining.
- 2) indicates a cause for uncertainty and variability in the number density of endangered species in each country by the application of the damage factor of domestic land alteration to overseas. However, for convenience of implementing damage functions, the rank correlation of variability in the number density of endangered species is underestimated.
- 3) indicates a cause for uncertainty in the damage actor of domestic land alteration. Tsim (s) indicates uncertainty caused by the application of the change rate in the number of individuals of the endangered species s. N_4 (Calanthe discolor) indicates the population of Calanthe discolor in a regional mesh. For details, see 2.10.

b. Damage factor for biodiversity

Compared with LIME 1 (Figure 2.11-13), trends in size between resources have been generally stable as a whole. With regard to some kinds of resources, statistical values (Table 2.11-12) and a distribution of cumulative frequency functions (Figure 2.11-12) were presented herein as examples. Because the damage factors under LIME 2 have wide variability, many of the damage factors under LIME 1 are within the interval between 30% and 70% around the median of the damage factors under LIME 2.

This wide variability was caused mainly by the variability in the increased extinction risk (UAR) per area of land alteration as shown in Table 2.11-13. With regard to resources imported from overseas, impact has been made also by the uncertainty caused by the application of the domestic UAR to overseas (correction rate). If there are many low-grade mines, such as copper mines, impact is made also by the viability in the grade and the hidden flow. On the other hand, with regard to rock, which is a domestic resource, the coefficient of variation has become relatively small.

The damage factor of wood has become larger than that of metal, largely because of difference in the area of land use per volume of resources as in the case of primary production (see a. above). Moreover, with regard to the damage factor for biodiversity, it is necessary to note that the amount of damage per land area (increase in the extinction risk) has been assessed on basically the same condition as the mining of underground resources – that is, the condition that all the individuals of (endangered species of) plants growing in land where wood is gathered should be lost. Because of such limitations, under LIME 2, as described above, wood is divided into that from natural forests and that from artificial forests, and an increase in the extinction risk is deemed to be caused by gathering of wood from natural forests. As a result, if it is unknown whether wood is from natural or artificial forests (due to insufficient inventory information), the probability distribution of damage factors has parts where the damage amount is zero and parts where it is large.

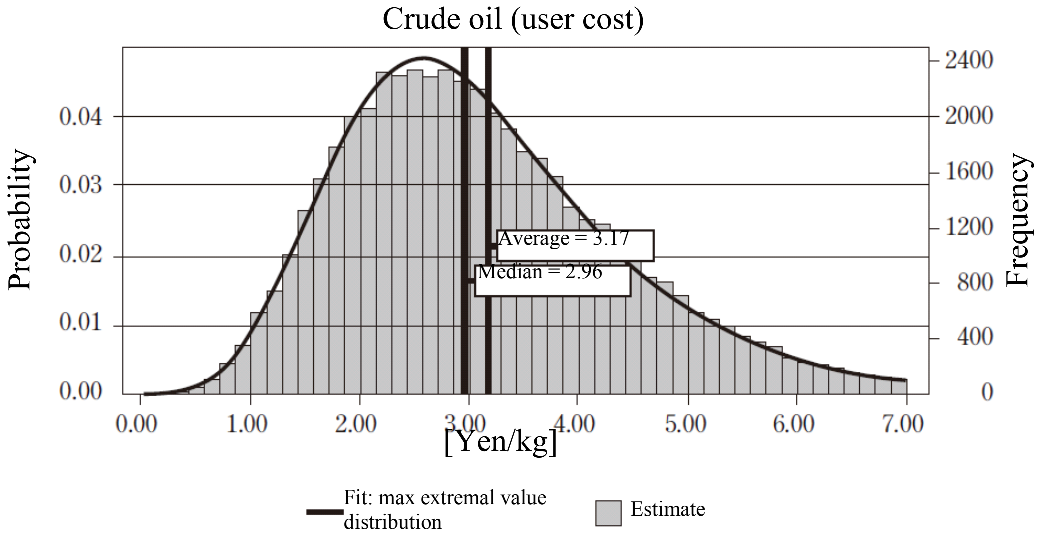

Figure 2.11-14: Prediction result of the probability density distribution of user costs of crude oil

Table 2.11-14: Result of uncertainty analysis of user cost Statistical value of (crude oil) (unit: yen/kg)

Statistical volume	Statistical value
Number of trials	50,000
Average	3.17
Median	2.96
Standard deviation	1.36
Dispersion	1.86
Kurtosis	7.19
Coefficient of variation	0.43
10% tile value	1.64
90% tile value	4.97
Average standard error	0.0061

Table 2.11-15: Rank correlation of causes for uncertainty of user cost of oil

Variables	Rank correlation coefficient
Growth of reserves in the world (excluding the US)	-0.61
Undiscovered reserves in the world (excluding the US)	-0.55
Change in oil price	0.50
Change in oil production	0.09
Undiscovered reserves in the US	-0.02

• The table shows the top five causes.

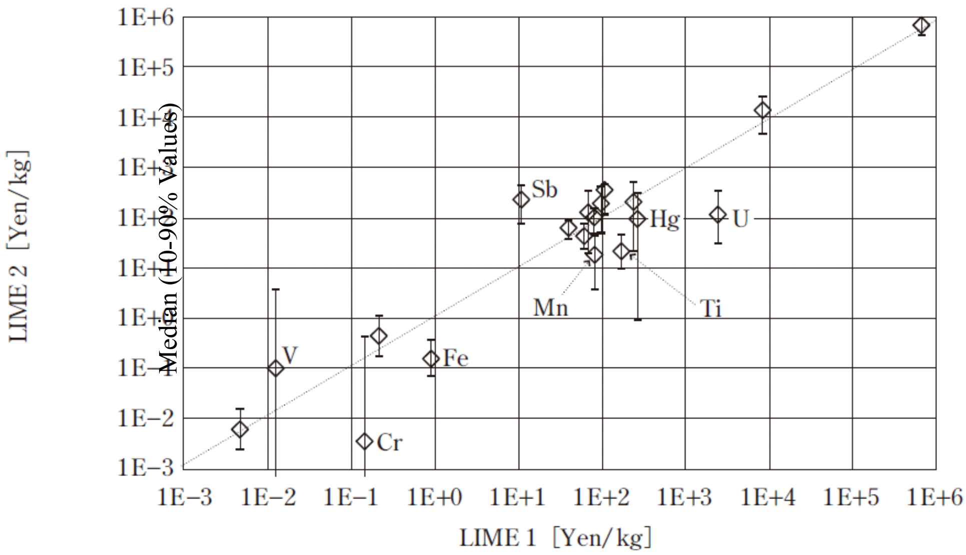

Figure 2.11-15: Comparison between LIME 1 and LIME 2 (user cost of resources)

c. Damage factor for social assets

As examples of uncertainty analysis results, Figure 2.11-14 and Tables 2.11-14 and 2.11-15 show a probability density distribution of user costs of oil, statistical values, and rank correlation coefficients with variables about which a probability distribution was established. During the calculation of user costs of oil, the user costs were reviewed by reference to the results of the estimation of ultimate reserves by USGS (2000) under LIME 2 as described above. In this latest estimation, however, because the "growth of reserves" in existing oil fields was included in addition to cumulative production volume, remaining reserves, and undiscovered minable reserves, this range of estimation was extracted as a cause for uncertainty.

Comparison in user cost between LIME 1 and LIME 2 indicates that some metals showed a great change. Among such metals, the user costs of niobium and vanadium were calculated larger than under LIME 1 because their production was on an upward trend in the second half of the 1990s. With regard to antimony also, the user cost was calculated larger because of the recent downward revision of the reserves. On the contrary, because the reserves of chromium were once estimated to be about a half as much as now, the user cost in LIME 2 was assessed at a smaller amount than before. Although the production or price of some metals seems to have risen sharply since 2005, such most recent trends have not been reflected.

In addition, there are some metals form which the value, source, and other information shown in the table of resources in the Resources and Energy Handbook used for LIME 1 is different from the information selected for LIME 2. Such metals include uranium (revised to greater reserves) and manganese (revised to a lower price).

Column 2.11-4

Way of thinking about the damage factor of deforestation under LIME

As described in the main text, under LIME, the inventory shows the status of forest management and it is assumed that the impact of deforestation is small when wood is gathered from stock for which appropriate (sustainable) management has been carried out and that forestation (on bare land) has a negative environmental burden.

Concretely, the following criteria are used for the classification in the inventory and the application of the damage factor. (1) Whether it is wood or a wood product. (2) The damage factor is used as it is if the forest is not managed or there is no information about management, while the damage is zero if sustainable management is carried out. If forestation is carried out after deforestation, but biodiversity is decreasing, it is inappropriate to regard the damage factor for the extinction risk as zero. In addition, if devastated land is forested for the purpose of nature restoration, a negative damage factor should be applied to the area of forestation. (3) Whether or not the country of origin is clear? Figure 2.11-A shows the flow of calculating the area of land use and selecting the damage factor according to these criteria.

An appendix hereto shows the damage factor in the case of wood volume concerning the criterion (1). It is assumed that the damage factor for biodiversity is zero if an artificial forest is deforested. This requires paying attention to the problem of whether any plant species that can become an object of damage assessment is growing in reality and the issue of whether the volume of past artificial alteration that might have been made if the artificial forest had originally been a natural forest should be allocated to the product system that uses the present artificial forest (Column 2.10-3: Points that need attention concerning land use inventory). With regard to metals and other mineral resources also, there is a similar problem in the allocation between primary and secondary metals.

This approach has the following problems and points that require attention. (1) Although sustainable management is taken into consideration, no consideration is given to any concrete method to guarantee it, such as the use of forest certification. (2) If sustainable management is carried out, any temporary impact is ignored and damage is assumed to be zero. Further consideration will be necessary in the future concerning primary production, including consideration for time-dependent changes in NPP according to forest growth and assessment related to maintenance (occupation) of land use. (3) No consideration is given to the vulnerability of places of production. When the vulnerability is incorporated, it seems necessary to consider both the biological viewpoint and the socio-economic viewpoint.

Inventory information				Calculation of area of land use and criteria for selection of damage factor
Wood volume	No management / no information	Country of origin is clear	→	Use of wood volume / area in the country
		Unknown	→	Use of value estimated from wood volume
	Sustainable management		→	Application of 0 as damage factor

Wood product volume	No management / no information	Country of origin is clear	→	Use of wood volume / area and log conversion rate of wood product in the country
		Unknown	→	Use of value estimated from wood product volume
	Sustainable management		→	Application of 0 as damage factor
Area of forest	Area of deforestation		→	Application of damage factor per area to area
	Area of forestation		→	Application of "negative " damage factor per area to area

Figure 2.11-A: Flow of determining a method for calculating area of land use

2.11.4 Procedures for impact assessment of resource consumption

Procedures for characterizing resource consumption and assessing damage from it can be described as follows. It is necessary to note that the impact assessment of resource consumption is carried out only concerning the amount of gathered natural resources (excluding the amount of recycled resources) in *Inv* (*X*), the inventory of the resource species *X*. This is important especially for damage assessment. For the inventory of forest resources, see Column 2.11-4 also.

With regard to mineral resources, it is necessary to clarify whether the inventory has been constructed in terms of the amount of metals or the amount of ores. Under LIME, the impact assessment factors have been calculated in terms of not the amount of ores but the amount of metals. Therefore, although the assessment factors should be applied after being multiplied by grade if the inventory value is expressed in terms of the amount of ores, this may expand errors in resultant values from damage assessment.

With regard to the characterization, the category index *CI* can be gained by Equation 2.11-8 from the viewpoint of the rarity of mineral resources. In addition, fossil fuels can be characterized not only by Equation 2.11-9, using the amount of energy as the index, but also by Equation 2.11-8.

Exhaustible resources (mineral resources): $$CI^{Depletion} = \sum_X CF^{Depletion}(X) \times Inv(X) \quad (2.11\text{-}8)$$

Fossil Fuels: $$CI^{Energy} = \sum_X CF^{Energy}(X) \times Inv(X) \quad (2.11\text{-}9)$$

Table 2.11-16: Formula for damage assessment in the impact category of resource consumption

DI (~~*Safe*~~) / Resources	*DI* (Social assets)	*DI* (Biodiversity)	*DI* (Primary production)
Fossil fuels † Mineral resources	$\sum_X DF_{Yen}^{Depletion}(X) \times Inv(X)$	$\sum_X DF_{EINES}^{Extraction}(X) \times Inv(X)$	$\sum_X DF_{NPP}^{Extraction}(X) \times Inv(X)$
Stone resources			
Forest resources			

† With regard to oil and natural resources among the fossil fuels, excluding coal, no damage factor is provided for biodiversity and primary production protected from the impact of land use (assessed as zero). For the reason, see 2.11.3 (2) a *1.

Several characterization factors have been suggested so far. Under LIME, the reciprocal of the amount of minable reserves, 1/R (normalized by antimony), was recommended as the characterization factor including both mineral resources and energy resources, $CI^{Depletion}$, and the amount of heat generation was recommended as the characterization factor that takes into consideration energy resources only, CI^{Energy}.

In addition, the index for endpoint approach – that is, the damage index *DI* (*Safe*) – can be gained from the damage factor *DF* (*Safe, X*) for each resource species *Inv* (*X*) and area of protection *Safe*. Although the formula is the same as that in the other impact categories, the damage factor for the area of protection of social assets is provided only concerning fossil fuels and mineral resources (Table 2.11-16). These damage indexes mean the amount of potential damage from land use for resource gathering in the case of the areas of protection of primary production and biodiversity, while they mean the assessed value necessary for investments in artificial assets to maintain monetary incomes from natural resource gathering permanently even after the gathering in the case of the area of protection of social assets. However, because the damage factor obtained from the setting of the discount rate changes as one of the characteristics of the user cost method used for the assessment of impact on social assets, the factor was presented herein in the case of a discount rate of 3% as the default.

The factor used for integration is $IF^{Resource}$ (*X*), the factor that integrates the impacts on social assets, biodiversity, and primary production. The single index *SI* can be obtained from *Inv* (*X*) and the integration factor $IF^{Resource}$ (*X*) for each resource. The result can be compared directly with or added to assessment results in other impact categories.

$$SI = \sum_X \left(IF^{Resource}(X) \times Inv(X) \right) \qquad (2.11\text{-}10)$$

The characterization factors $CF^{Depletion}$ (*X*) and CF^{Energy} (*X*) are listed in Appendix A1, the damage factor $DF^{Resource}$ (*Safe, X*) is listed in Appendix A2, and the integration factor $IF^{Resource}$ (*X*) is listed in Appendix A3.

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2.12 Waste

Changes under LIME 2
- Uncertainty assessment of damage factors was carried out. Uncertainty includes geographical variability (uncertainty about at what final disposal site the waste entered in the inventory is buried).
- A review of the fundamental damage functions for the impact category of land use was reflected in the damage factors to biodiversity and primary production due to waste landfill.
- As a damage factor to social assets, assessment by user cost was added concerning reduction in the remaining capacity of final disposal sites.

2.12.1 What phenomenon is the environmental impact of waste?

(1) Causal relationship between waste and environmental impact

In Japan, recently, various problems regarding waste have drawn social attention. One of the reasons for this is expectations for and friction of a physical approach to a sustainable society that can be expressed as a recycling-based society. The other reason is anxiety about environmental destruction due to illegal disposal and the environmental impact of waste disposal.

The latter brings about the feeling of evasion from waste and waste disposal facilities (intermediate treatment facilities and final disposal sites (landfill disposal sites)). Especially if the location of waste treatment facilities is separated from the district where waste is produced, the sense of burden and the sense of unfairness increase in the district where the facilities exist, and as a result it has been difficult to locate new facilities. Under such circumstances, with regard to industrial waste (mainly the law-specified 20 types of waste that are discharged from agriculture, forestry, fisheries, mining, manufacturing, construction, and other industries), it has been pointed out that insufficient disposal capacity becomes a cause for illegal disposal, creating a vicious circle (Central Environment Council 2004).

Figure 2.12-1 shows the causal relationships among the environmental impacts related to such waste. Of course, there are various types and properties of waste, ranging from soil-like waste to highly toxic waste, and various methods to dispose of waste. In addition, because various substances are included in waste, while some types of waste can be rendered harmless or stabilized through treatment, some substances are generated unintentionally.

The figure shows some of the environmental impacts and causes concerning incineration facilities (Figure 2.12-1 (5)) and landfill disposal sites (Figure 2.12-1 (6)), typical facilities for disposing of “refuse” (urban refuse) among general waste discharged from homes and offices, including refuse that may be produced when accidents occur (excluding labor accidents).

The Waste Management Act (Waste Management and Public Cleansing Act) roughly classifies waste into the above-mentioned industrial waste and other general waste (refuse and human waste discharged from homes, shops, and offices). Disposing entities and disposal facilities basically differ between the two. Because of this, under LIME also, characterization factors and damage factors have been presented after classification into the two types of waste.

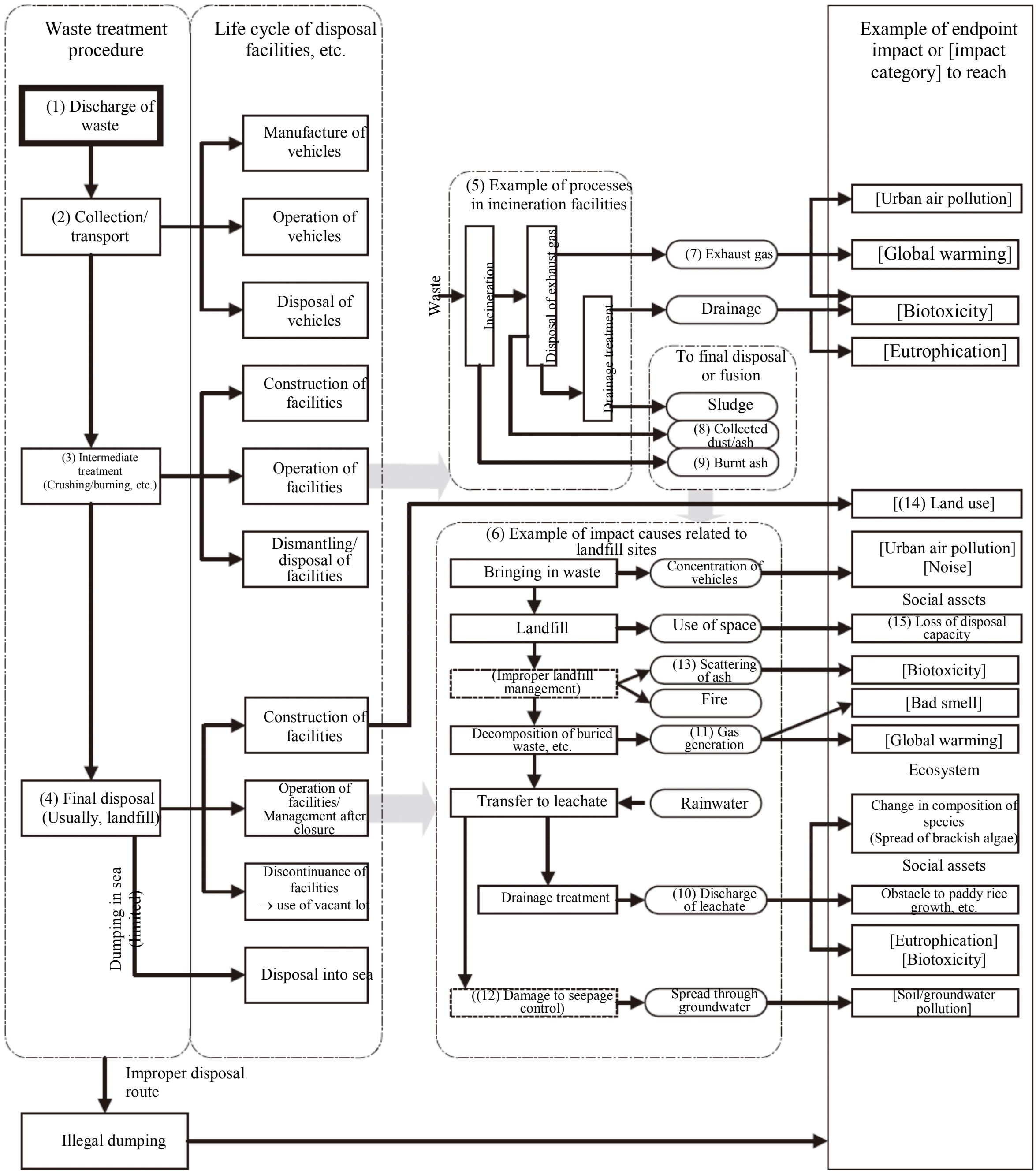

Figure 2.12-1: Causal relationships of environmental impacts of waste

The parenthesized numbers (1) to (15) are referential numbers for the main text.

a. Waste incineration facilities (Figure 2.12-1 (5))

With regard to exhaust gas from waste incinerators (Figure 2.12-1 (7)), the Air Pollution Control Act regulates the emission of sulfur oxide, dust, hydrogen chloride and nitrogen oxide, while the Act on Special Measures against Dioxins regulates dioxin. According to Japan's "Dioxin Emission Inventory" (Ministry of the Environment 2007a), although the emission of dioxin from waste incinerators to the atmosphere was more than 7,000 grams in FY1997, it greatly decreased to about 200 grams in FY2006.

With regard to unregulated substances, a survey conducted by the (then) Ministry of Health and Welfare from 1995 to 1998 found the following facts concerning exhaust gas from urban waste incineration facilities: “Although many toxic substances were detected, their levels were far lower than the regulatory levels fixed by Germany/Holland and Kyoto. In addition, some toxic substances (mercury and hydrogen fluoride) almost reached the levels or exceeded them” (Tanaka 2000). After this survey, facilities, such as bag filter dust collectors, were remodeled in Japan as a measure to reduce the emission of dioxin. Some reports (Kida et al. 2003, Tejima et al. 1994) show cases where the efficiency for removing mercury improved after the remodeling.

Many toxic substances in exhaust gas move into dust collected by dust collectors (Figure 2.12-1 (8)). Generally, dust is hygroscopic and scatters and contains heavy metals contained in products (Nakamura 1994) more densely than does burnt ash (main ash and residual ash) (Figure 2.12-1 (9)). Dust has been designated by law as specially controlled waste (because of its toxicity). Because of this, dust should be disposed of by designated methods, such as melt-solidification, cement solidification, and chemical treatment (heavy metal fixative treatment). The Act on Special Measures against Dioxins specifies the amount of dioxin included in dust and burnt ash related to waste incinerators.

b. Landfill sites (Figure 2.12-1 (6))

One of the environmental impacts related to landfill is alteration of nature due to construction of landfill sites. In addition to this, neighboring people are afraid of the following concerning the construction of a landfill site: (a) the possibility of groundwater pollution from buried matters; (b) concentration of waste transporting vehicles (air pollution, noise, etc.); (c) salt damage in places into which leachate is discharged (damage to growth of paddy rice, spread of brackish algae, etc.); and (d) scattering of burnt ash that emits bad smell and contains toxic substances. As objects of environmental impact assessment, the “Manual of Environmental Impact Assessment of Final Waste Disposal Sites” (Japan Waste Research Foundation 1999) specifies the general environmental impact causes and acts that accompany final disposal site projects and the elements that receive impact.

Landfill disposal standards have been established for each type of waste (Nakasugi 1994) and types of landfill sites that can accept waste differ according to the type and properties of waste. With regard to industrial waste, if it is toxic and does not meet the standards, it should be sent to isolated-type disposal sites. Glass waste and four other specified types of waste whose properties are stable and which are unlikely to give damage to the living environment through the pollution of groundwater by leachate (the “stable five items”) should be sent to inert-type disposal sites. The other types of waste should be sent to controlled-type disposal sites. Basically, general waste (refuse) should be disposed of at controlled-type disposal sites. With regard to the items allowed to be buried in inert-type disposal sites, disposal of shredder dust, residue after the crushing of automobiles, and the like has been prohibited in the sites since April 1995, and disposal of waste plaster boards has basically been prohibited in the sites since June 1998. In this way, changes were made with the strengthening of environmental conservation.

The structural and maintenance standards for these disposal sites are specified in the Order Determining Technical Standards Concerning Final Disposal Sites of Industrial and Non-Industrial Waste” (the so-called “Joint Order”). For example, it is provided that discharged water should meet the drainage standards specified in the Water Pollution Control Act through the construction of facilities for disposing of leachate generated in controlled-type disposal sites.

In 1997, the Ministry of Health and Welfare's survey found that, among the 1,901 facilities for final disposal of general waste in Japan, 538 facilities (28%) did not have seepage control or leachate treatment equipment, excluding the facilities that only treated waste that did not require the treatment of leachate, such as glass dust. A notification (Ministry of Health and Welfare 1998) was issued to the prefectures to have them give guidance about proper treatment of municipal final disposal sites for general waste.

In Japan, the final disposal sites have been developed based on the idea of "semiaerobic landfill structure" mainly for general waste. In this structure, air is supplied in landfill layer through leachate collection pipes to eliminate leachate promptly, and it widely improves the water quality (biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total nitrogen (TN)) of leachate (Figure 2.12-1 (10)), compared with anaerobic landfill, and facilitates the decomposition of organic substances in an aerobic area (Generating gases (Figure 2.12-1 (11)) include carbon dioxide (CO_2) and methane). In an anaerobic area, if a heavy metal is ionized, it forms hardly-soluble sulfide because of the action of hydrogen sulfide and remains within the landfill layer in a comparatively stable form (Landfill System and Technologies Research Association of Japan 2000, Tanaka 1993). According to research reports, although dioxin brought into disposal sites cannot be easily decomposed, is stored for a long time, and is discharged into the environment mainly through leachate (Noma et al. 2000), it is removed together with suspended solid (SS) in water treatment facilities (Noma et al. 2002).

With an increase in the waste incineration ratio and the strengthening of exhaust gas treatment, the ratio of combustibles decreased, while the ratio of incineration residue and incombustibles increased and the amount of calcium and salt included in incineration residue increased. Because their ions dissolve in water, it has become a challenge to develop measures to treat salt during water treatment.*[11] Moreover, it has been found that a comparatively high density of boron is contained (National Institute for Environmental Studies 2001). With regard to the discharge of unregulated substances from final disposal sites, there are research reports by Fukui et al. (1994), Nakasugi (1993), and Yasuhara et al. (2000, 2003).

In addition, when campaigns against the construction of facilities became heated, a problem was presented concerning damage to seepage control, an important component of a disposal site. In 1998, the Joint Order was revised (Ministry of Health and Welfare 1998) to improve the safety of seepage control (structure that prevents exchange between water in a landfill site and water in the surrounding environment) (Figure 2.12-1 (12)).

Tojo et al. (1999) investigated the density of heavy metals in soil around disposal sites. According to their report, because the density of metals in soil changed around disposal sites where daily earth cover was not carried out, unless appropriate landfill measures are taken, burnt ash is highly likely to scatter around (Figure 2.12-1 (13)).

(2) The impact category to which the environmental impact of waste belongs and the endpoints

[11] For example, "Special Issue: The Recent Technology or Treatment of Leachate in Final Waste Disposal Sites" (Environmental Conservation Engineering (2002), 31 (8)) and "Special Extra: Technology for Removal of Salt during Leachate Treatment in Final Disposal Sites" (Journal of Resources and Environment (2002), 38 (2))

a. Substances discharged into the environment from waste disposal facilities

Under LCA, exhaust gas and noise from running vehicles during the process of waste collection and transport, and exhaust gas and drainage from incineration facilities can be measures by inventory analysis, like exhaust gas and noise from running vehicles and manufacturing factories during the process of distributing products. Therefore, the necessity for dealing with the impact category of waste independently during impact assessment (damage assessment) seems to be low. In the LCA project, the inventory working group WG-2 has created a life cycle inventory (LCI) methodology for the processes of recycling and disposal and has been collecting inventory data.

On the other hand, the same is basically true of methane gas and leachate from landfill disposal sites. It seems all right to measure them as output to the environment and assess them in other impact categories, such as global warming (Yamada 2004). However, this process is different from the other processes of the product lifecycle, in that the impact of discharge into the environment continues for a long time. This is sometimes presented as a methodological issue under LCA (Hellweg et al. 2003).

Generally, it can be said that the environmental impact of substances discharged into the environment during the treatment of waste basically belongs to other impact categories, such as global warming and toxic chemicals. Therefore, the contents of the preceding clauses were arranged from the viewpoint of which impact categories can be related to the substances discharged during the treatment of waste. The results are shown in Table 2.12-1.

Table 2.12-1: Discharge into the environment from waste treatment facilities from the viewpoint of endpoints and impact categories

Examples of endpoints/impact categories	Examples of discharge into the environment
Impact category of urban air pollution	Exhaust gas from incineration facilities (such as nitrogen oxide and hydrogen chloride)
Impact category of global warming	Exhaust gas from incineration facilities (such as carbon dioxide and dinitrogen monoxide) Organic decomposition gas from landfill facilities (such as methane)
Impact category of toxic chemicals Impact category of biotoxicity	Exhaust gas from incineration facilities (such as dioxin and mercury) Water discharged from landfill facilities (for a long time)
Salt damage (damage to paddy rice growth, changes in structure of species (spread of brackish algae, etc.))	Water discharged from landfill facilities (salt)

- The density and volume of discharge may greatly differ among facilities according to the existence, type, and level of environmental conservation measures. As described in the main text, environmental conservation measures have been strengthened mainly for newly established facilities.
- Discharge can be divided into two types: discharge due to the inclusion of causative substances in waste, such as carbon dioxide generated due to incineration of plastics; and discharge incidental to treatment, such as thermal NOx generated due to incineration and carbon dioxide generated due to incineration of fossil fuel for auxiliary heating.
- Implementation of LCA requires clarification of treatment of biomass-derived carbon dioxide concerning the impact category of global warming (such as incineration of biomass and carbon dioxide among the cracked gases from landfill facilities).

b. Land alteration due to construction of waste treatment facilities (Figure 2.12-1 (14))

A typical case where the construction of treatment facilities became a problem in relation to the conservation of the ecosystem was a plan for the construction of a marine disposal site that accompanied the reclamation of a tideland. According to the "Final Disposal Sites in Japan 2000" (Landfill System and Technologies Research Association 2000), if the total number of landfill disposal sites are classified by location, 70% of them are located in mountainous areas, following by 28% located on level land. Because marine ones (2%) were constructed as disposal sites for major cities that have seaside areas, their sizes are large.

Waste disposal has traditionally been municipalities' legal obligation, and disposal within the jurisdiction of each municipality has been widely recognized as a political principle. Because of this, there are many waste disposal facilities (about 1,700 incineration facilities and about 2,300 landfill disposal sites) (Environmental Sanitation Facilities Development Association 2000).

Therefore, among the landfill sites for general waste, 60% are small ones with an area of less than 1 ha. The average landfill area is 2.24 ha. In terms of landfill capacity, disposal sites with a capacity of 300,000 m^3 occupy 90% and the average landfill capacity is 190,000 m^3. Given these figures, the average landfill depth is 8.5 m (Landfill System and Technologies Research Association 2000). In other words, the landfill of waste of 1 m^3 requires a landfill area of about 0.12 m^2 even if consideration is given only to landfill space.

c. Loss of space for waste disposal (landfill) (Figure 2.12-1 (15))

As described in b. above, the landfill of waste is accompanied by not only the alteration of nature but also the problem of insufficient disposal capacity.

Hosoda (1999) pointed out that final disposal sites cannot be created indefinitely and, in this sense, they are exhaustible resources, and considered the application of the framework of resource economics. The book specifies greatly different points from ordinary exhaustible resources, regarding recycling technology as backstop technology for final disposal, and states that the value of rarity of final disposal sites for general waste, which are managed by the use of tax, has not been commercialized. For the economic value of exhaustible resources, see 2.11.3 (7) also.

2.12.2 Characterization of waste

(1) Characterization factor of waste under the existing LCA method

Under the LCA method in Japan, because of the current environmental problems, there are many cases where waste is regarded as an impact category, and waste is taken into consideration in some impact assessment methods. In foreign countries, however, few overseas impact assessment methods take waste into consideration (Environment Committee of Industrial Structure Council 2001).

Of the impact assessment methods in Japan, the environmental load point (ELP) method and the time consumption method characterize the waste-related impact categories by totaling the weights of various types of waste. The subjective assessment of the number of years until the occurrence of crisis and the criticality concerning solid waste under the time consumption method is carried out concerning the problem of depletion of waste disposal sites (Yasui et al. 2000).

In the case where the comparative risk method was applied to the impact assessment of packaging (Terazono et al. 1999), areas of protection were selected for 15 types of environmental problems and four impacts in a comparative risk workshop. Among them, the following are specified as environmental loads and problems related to waste: emissions of waste → the problem of mass production, consumption, and disposal; landfill disposal volume → large-scale natural development; and incineration disposal volume and landfill disposal volume → the problem of location of troublesome facilities. They are weighted by relatively many aspects and stages concerning waste. Weight is the unit for the characterization by this method.

When Inaba et al. (1999) made suggestions about the index of environmental capacity consumption by setting of environmental capacity for each region, they made a suggestion concerning the space resource consumption that accompanies the landfill of waste. The number of remaining years (remaining capacity of disposal site ÷ annual waste landfill) was rejected because it is an index that indicates the degree of tightness of a final waste landfill disposal site – that is, the impact of brought-in waste on the disposal site itself, not the impact of the construction of a disposal site. A scenario was created where the landfill of waste is regarded as the consumption of space resources and some of the space resources remaining in the region, such as forests and fields, are allowed as land that can be used for the construction of a waste disposal site, and the allowed amount was set up as the environmental capacity of waste landfill.

In addition, there are the following cases; a case where the total annual amount of discharged waste in Japan was used for normalization (Akimoto et al. 2000); a case of easing the lack of disposal sites by reduction of the amount of landfill waste (increase in the number of remaining years) (Ishizaka et al. 2000); and a case where assessment was carried out in the impact category of "landfill consumption" from the viewpoint of tightness of landfill sites under the Distance-to-Target (DtT) method (Hirai et al 2001). (In these cases, characterization was carried out in terms of weight or volume.)

Based on what have been described above, if waste is selected as an impact category, it can be said that there are the following choices for characterization among the data items: (a) the generation amount of waste (Figure 2.12-1 (1)) or (b) the final disposal (landfill) amount of waste (Figure 2.12-1 (4)).

(a) focuses on whether the amount of generated waste is large or small. This can be said to be the setting of an index that considers social influence, taking into account the social situation where lack of disposal facilities and new construction of them tend to receive an objection from local people. However, except for illegal dumping, generated waste is not directly discharged into the environment. In addition, if characterization is made at the time of generation, the number of impact categories to be integrated will increase due to changes in the form of waste through recycling and incineration and the environmental impacts of these acts.
On the other hand, (b) leads to landfill, an act of altering nature (land and sea), and is closer to environmental impact. Therefore, characterization that takes (b) into consideration is desirable for the damage-calculating impact assessment method.

With regard to the range of waste to be covered, if environmental impact proportional to the landfill amount is dealt with as a problem, there is no reason for limiting it to the "waste" defined in the Waste Management Act. Construction waste soil and the like should be included in the waste to be measured. On the other hand, if attention is paid to qualitative differences (such as stability and innocence) among buried things, it is necessary to distinguish toxic waste from glass or the like. For example, if the spread of toxic substances from a landfill site is a problem, the impact of glass should be characterized as zero. That is, the range, classification and characterization of waste to be covered are difficult to determine unless there is a viewpoint of damage assessment as to what environment impact should be focused on.

(2) Characterization factor of waste under LIME

Under LIME, as described below, on the assumption that the spread of substances from a disposal facility, such as a landfill site, is measured as the inventory for another impact category, alteration of nature due to the construction of a landfill site (land use) was deemed to be the object of assessment. Therefore, the characterization factor of waste is any of the following: (1) landfill weight; (2) landfill volume; and (3) area of landfill (area of land use). Because the inventory is usually expressed by mass unit, uncertainty increases in order of (1) → (2) → (3). (1) does not reflect the quality of waste to be buried. On the other hand, (1) is convenient in that the unit is the same as that of the future target of the final disposal amount under the basic policies based on existing waste-related statistics, the Basic Plan for Establishing Recycling-Based Society and the Waste Disposal and the Waste Management Act. On the other hand, (2) and (3) are consistent with the concepts of the characterization and damage assessment of land use. (3) is characterized by enabling comparison with other impact categories, such as resource consumption and land use. However, because the area of land use was not recommended as the characterization factor for the impact category of resource consumption, which leads to land alteration in the same way, there is no reason for positively selecting (3) for waste. Therefore, (2) can be recommended as the characterization factor of waste. In this case, it is possible to regard (2) as the characterization index of loss of landfill space.

Under LIME 1, bulk density (weight → volume conversion factor) at the time of landfill by type of general waste was set up from Tanaka (2000). If the type is unknown, 0.8163 was used, which is the landfill waste ratio used by the Ministry of the Environment for calculating the remaining capacity of a final disposal site for general waste. With regard to industrial waste, reference was made to values specified in "Waste Handbook" (Japan Society of Waste Management Experts 1997) and "Guidelines for Disposal of Construction Waste" (Ministry of Health and Welfare 1990). With regard to various types of sludge (other than construction sludge), values converted based on disposal facilities' scope of permission under the Waste Management Act were used.

Among the environmental loads at the time of landfill, the volume or area of products, etc. treated as space consumption was set up as an inventory data item also by WG-2, the inventory workgroup for the LCA project (Japan Environmental Management Association for Industry 2003).

2.12.3 Damage assessment of waste

(1) Basic policy for calculation of damage factor and assessment of uncertainty

Wada et al. (1996) arranged the environmental impact of final waste disposal from the viewpoint of LCA. According to the result, they mentioned the following as important items: (1) the environmental burden that accompanies the operation of equipment used for landfill in a final disposal site; (2) the environmental burden of substances discharged from waste buried in a final disposal site; and (3) the environmental burden of space occupation for final disposal (environmental resources lost due to occupation of a part of the natural environment). Under LIME, a policy was established to deal with the ecosystem impact related to the alteration of nature and the occupation of space due to the construction of a final disposal site, which falls under (3). (1) and (2) are items to be grasped by inventory analysis and assessed in other impact categories (example: the discharge of methane from buried things (Yamada 2004) was taken into consideration for the impact category of global warming).

Table 2.12-2 shows the objects of calculation of damage functions under LIME, and Figure 2.12-2 shows the flow of calculation. Under LIME 2, the impact of loss of disposal space was added to the objects of assessment by the user cost method as in “2.11 Resource consumption.”

Table 2.12-2: Category endpoints of waste and objects of calculation of damage functions

<table>
<tr><th>Area of protection</th><th colspan="2">Category endpoint</th><th colspan="2">Object of calculation of damage function</th></tr>
<tr><td>Human health</td><td colspan="2">(Impact of substances discharged at the time of waste disposal)</td><td>—</td><td>Assessor’s consideration in other impact categories, such as toxic chemicals</td></tr>
<tr><td rowspan="2">Social assets</td><td>Landfill space (Exhaustible resources)</td><td>Loss / tightness of disposal space</td><td>○</td><td>User cost</td></tr>
<tr><td colspan="2">(Impact of substances discharged at the time of waste disposal)</td><td>—</td><td>Assessor’s consideration in other impact categories</td></tr>
<tr><td rowspan="4">Primary producton</td><td rowspan="3">Terrestrial ecosystem</td><td>Decline in NPP during construction of disposal site</td><td rowspan="2">○</td><td rowspan="2">Net primary production of vegetation (Regarding both periods as the period of maintenance of land use)</td></tr>
<tr><td>Decline in potential NPP during waste landfill and until discontinuance</td></tr>
<tr><td>Decline in potential NPP during hypothetical recovery period after discontinuance</td><td>○</td><td>Net primary production of vegetation</td></tr>
<tr><td colspan="2">(Impact of substances discharged at the time of waste disposal)</td><td>—</td><td>Assessor’s consideration in other impact categories</td></tr>
<tr><td rowspan="2">Biodiversity</td><td>Terrestrial ecosystem</td><td>Change in composition of plant species</td><td>○</td><td>Extinction risk of vascular plants</td></tr>
<tr><td colspan="2">(Impact of substances discharged at the time of waste disposal)</td><td>—</td><td>Assessor’s consideration in other impact categories</td></tr>
</table>

- With regard to primary production and biodiversity, assessment was made via the impact category of land use (for details, see Table 2.10-3).
- The impact of substances discharged at the time of waste disposal is illustrated in Table 2.12-1.

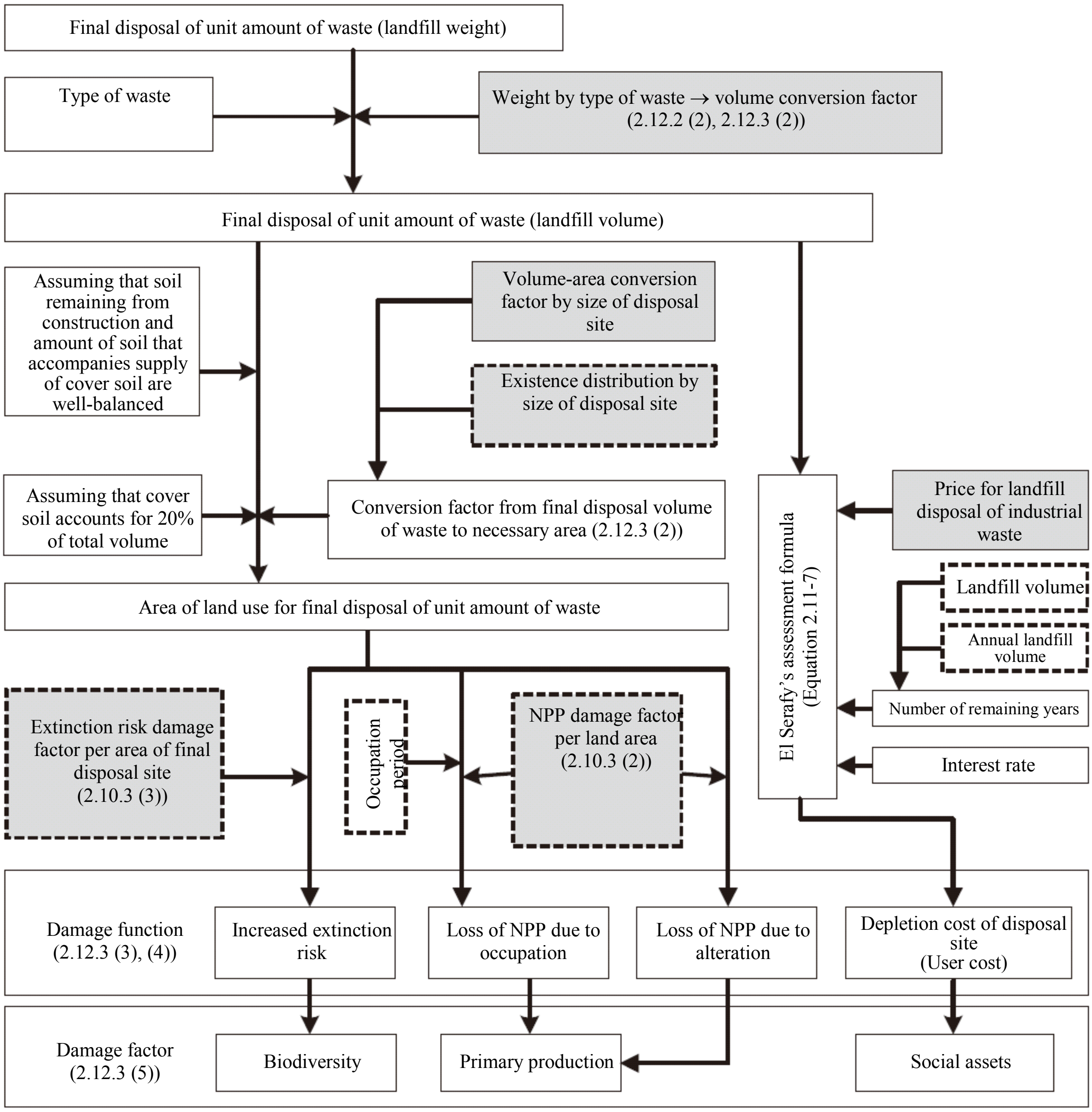

Figure 2.12-2: Calculation flow of damage factor of waste

Shaded parts indicate causes for which the uncertainty of parameters is taken into consideration. Bold dotted lines indicate causes for which the variability is taken into consideration.

Table 2.12-3 shows possible causes of uncertainty of damage functions (especially, errors and variability in the estimation of parameters) and how to treat them during the uncertainty assessment. Among the parameters considered during the uncertainty assessment, those included in Figure 2.12-2 are indicated by shading and bold dotted lines.

(2) Arrangement of information on land use that accompanies final disposal of a unit volume of waste

In the inventory, the final disposal amount of waste seems to be often expressed by not volume but weight. Under LIME 2, with regard to conversion from volume to weight by type of waste, after documents other than those referred to when the characterization factor was set up (see 2.12.2 (2)) (Sakai et al. 1998, Japan Waste Management Association 1999) were additionally collected and arranged, and a uniform distribution was established by the use of the minimum and maximum values specified in the documents concerning the same type of waste. According to the result, the maximum value is more than twice as large as the minimum value concerning plastic waste. With regard to cement solidified products, molten slag and soot dust, no probability distribution was established because the uncertainty related to them is relatively less than that related to other types of waste. If the type of waste is unknown, the extent of uncertainty was widened by the use of a triangular distribution whose upper and lower limits are the minimum and maximum values of all types, respectively.

Next, estimation was made about the state of land use that accompanies final disposal of 1 m^3 of waste. By reference to the "Annual Report on Waste Disposal Facilities 1999" (Kankyo Sangyo Shinbun 2001), final disposal sites for general waste in Japan (2,460 facilities) were arranged in order of landfill area, and the characteristics of the top ten facilities were grasped. With regard to the facilities other than the top ten, 45 facilities were sampled at regular intervals and their characteristics were grasped.

According to the double logarithmic chart that indicates the relation between landfill area and landfill area ranking, it was observed that about 1,500 higher-ranked facilities follow the power law, but the sizes of lower-ranked facilities decrease sharply. A similar tendency was observed concerning the relation between landfill volume and landfill area ranking (Figure 2.12-3).

Table 2-12-3: Main causes of uncertainty and policies concerning damage functions of waste

Main possible causes of uncertainty	Policies for uncertainty assessment
Geographical variability of inventory (unknown as to what disposal site relates to the landfill amount reported in inventory)	Carry out assessment on the assumption that there are 2,460 disposal sites in Japan and waste is buried in any of them with a probability proportional to their total capacity.
Volume-weight conversion by type of waste	Set up width based on differences among values specified in different documents.
Conversion rate of total volume of landfill disposal sites and disposal volume of waste into area	Assess estimated errors in parameters for regression equation used for estimation under LIME 1 for each disposal site. †1
Period of land use as final disposal sites	Set up a period based on the number of years of operation of disposal sites for which landfill is completed (taking also into consideration estimated errors in parameters). Separately, consider uncertainty during period between operation and discontinuance. †1
NPP damage amount per area of final disposal site	Use the result of examination of "2.10.3 Damage assessment of land use." †2
Extinction risk damage amount per area of final disposal site	Use the result of examination of "2.10.3 Damage assessment of land use." †2
Price for landfill of waste	Set up a price based on several companies' range of price.
Number of remaining years of landfill disposal sites (total landfill volume, annual landfill volume)	Errors in future estimation (smoothing) based on past data.

†1 Because the geographical variability of the parameters is assessed for the damage functions, both the variability and the estimation errors are assessed.

†2 Parameters whose geographical variability has already been assessed outside of the damage functions (damage functions for other impact categories)

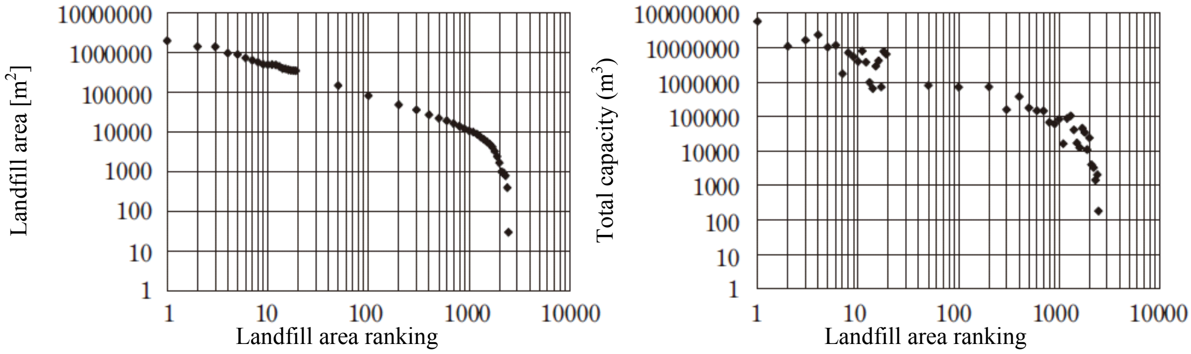

Figure 2.12-3: Relation between landfill area ranking and landfill area (left) and total capacity (right)

Next, according to the value calculated by dividing the landfill area by the total volume (area-volume ratio) – that is, the result of calculation of the landfill area consumed for disposal of 1 m^3 of waste (necessary landfill area), it was found that, the lower the rank in landfill area, the larger the necessary landfill area. In addition, from the viewpoint of location, the necessary landfill area tends to be larger on level ground than in mountains. On the assumption that the ratio of the landfill area to the site area of the final waste disposal site is 0.4 in mountains and 0.7 on level ground (both are from Tanaka (2000)) and 1.0 on the sea surface, the landfill area was converted to the site area, and a distribution of site area necessary for landfill of 1 m^3 of waste (assumed as altered area) was established. Based on the result, it was deemed that the value calculated by dividing the area of land use in a final disposal site by the whole landfill capacity did not depend on location (Figure 2.12-4).

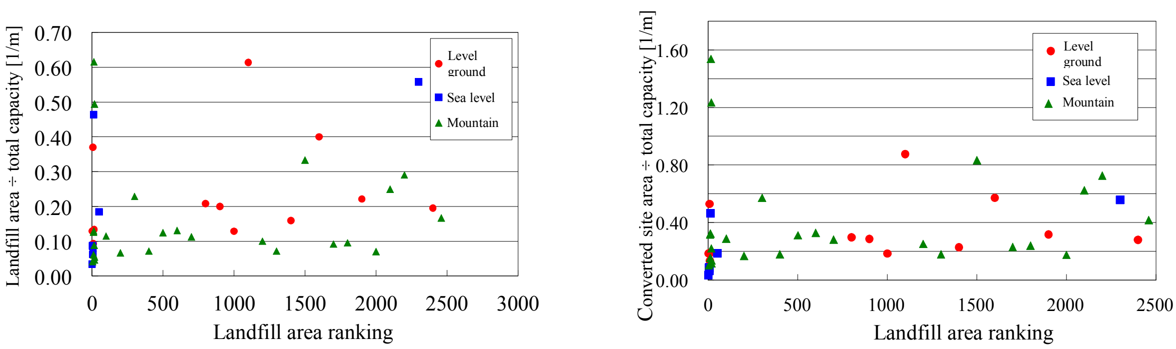

Figure 2.12-4: Relation between landfill area ranking and volume-area ratio

- The conversion ratio to site area (landfill area ÷ site area) is 1.0 for sea level, 0.7 for level ground, and 0.4 for mountain.

Based on the results above, an estimation equation was formulated concerning the whole landfill capacity and the converted site area divided by the whole landfill capacity in relation to landfill area ranking (Table 2.12-4).

On the assumption that the final waste disposal was allocated in proportion to the whole landfill capacity of each disposal site in Japan under LIME 1, the allocation rate to each disposal site was calculated based on the result of Table 2.12-4. Each disposal site's converted site area divided by the whole landfill capacity (area conversion rate) was multiplied by the allocation rate (Figure 2.12-5), and the results were totaled to calculate the necessary site area for final disposal of 1 m^3 of waste in Japan. The necessary site area was calculated to be 0.20 m^2/m^3. *[12] Under LIME 2, as described in (1) above, on the assumption that it was unclear in what disposal site waste was buried, this allocation rate was assessed as the probability of occurrence of in what disposal site the waste entered in the inventory as that to be finally disposed of was buried. Figure 2.12-5 also shows the range of the area conversion rate corresponding to the probability of occurrence.

Moreover, consideration was given to cover soil, which accounted for about 20% of the quantity of disposal (on the basis of volume).

In addition, under LIME 1, it was assumed that the period of land use by a final waste disposal site was 30 years, which consisted of 2 years for construction, 18 years for completion of landfill, and 10 years for discontinuance. Under LIME 2, with regard to the period until the completion of landfill, by reference to the results of the Ministry of the Environment's survey on the actual condition of general waste disposal (the FY1998 version, which is similar to the FY1999 annual report on facilities referred to under LIME 1), a distribution of the number of operating years concerning about 200 disposal sites where landfill was completed and the ending year of landfill was identified was established by size of landfill capacity. In addition, with regard to the period until discontinuance, by reference to Tanaka (2000), a uniform distribution between 5 years (no regulation on COD, T-N) and 15 years (regulations on COD, T-N exist; landfill sites for organic substances) was established.

Table 2.12-4: Estimates of each disposal site's whole landfill capacity and its converted site area divided by the whole landfill capacity

<table>
<tr><th>Landfill area ranking</th><th>Whole landfill capacity</th><th>converted site area ÷ whole landfill capacity</th></tr>
<tr><td>1-10</td><td colspan="2">Values specified in facilities' annual reports were referred to in detail because of large impact on the whole.</td></tr>
<tr><td>11-100</td><td rowspan="2">Regression analysis is conducted from sampling data (Figure 2.12-3) and volume was estimated from ranking.
Log (capacity) = α − β (log (ranking) − C)
In this equation, α = 5.372 (SE = 0.063),
β = 0.939 (SE = 0.073), C=2.345</td><td>Application of data in the right of Figure 2.12-4 at equal probability
(LIME 1: 0.20)</td></tr>
<tr><td>101-2000</td><td>Application of data in the right of Figure 2.12-4 at equal probability
(LIME 1: 0.30)</td></tr>
<tr><td>2001-2460</td><td>Same as above. α = 3.370 (SE = 0.139),
β =17.964 (SE = 4.428), C=3.350</td><td>Application of data in the right of Figure 2.12-4 at equal probability
(LIME 1: 0.50)</td></tr>
</table>

- Under LIME 2, a normal distribution based on standard errors was applied to the parameters of the regression equation for calculation of whole landfill capacity
- Under LIME 1, the amount calculated by dividing the converted site area by the whole landfill capacity is almost equal to the median of the distribution of data.

[12] With regard to final disposal sites for industrial waste, it was confirmed that distributions of the whole capacity and the area-volume ratio of the 16 inert-type facilities and the 10 controlled-type facilities in Chiba Prefecture are similar to those of the final disposal sites for general waste in Japan.

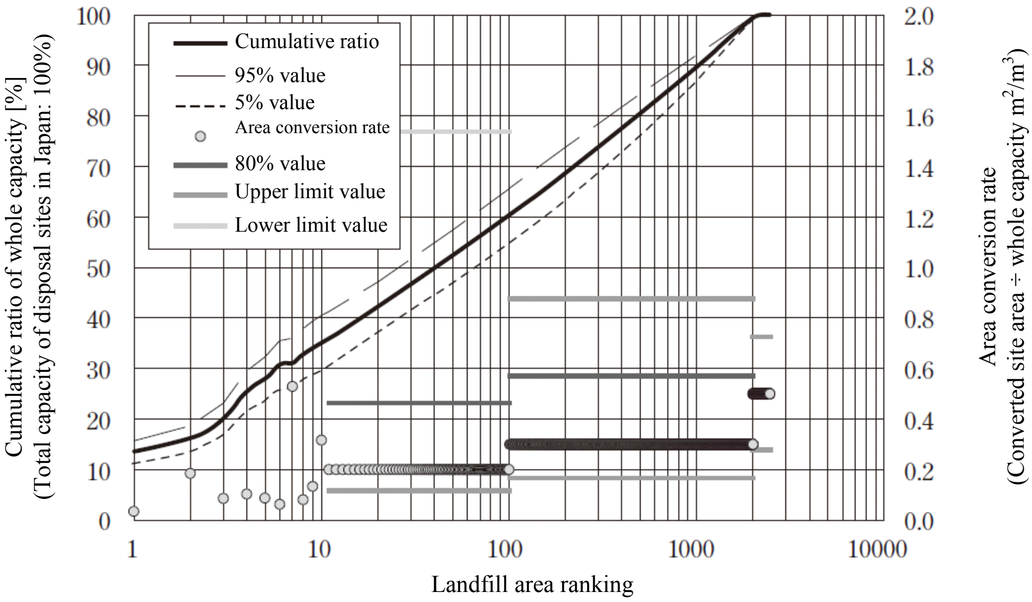

Figure 2.12-5: Landfill area ranking, cumulative ratio of whole capacity, and area conversion rate

The cumulative ratio of the whole capacity of each disposal site is used as the allocation ratio (LIME 1) or as the probability of occurrence in each disposal site corresponded to the inventory (LIME 2).

(3) Primary production and biodiversity: damage functions of waste

The damage function of primary production ($DF_{NPP} = DF_{NPP}^{Trans} + DF_{NPP}^{Occ}$) and the damage function of biodiversity (DF_{EINES}) that accompany the final disposal of a unit amount (1 kg) of waste – that is, the amount of damage – was calculated by the following equation:

DF_{NPP}^{Trans} [kgDW/kg] = area of land use [m^2]
× amount of damage to primary production due to alteration of unit land area [kgDW/m^2] (2.12-1)

DF_{NPP}^{Occ} [kgDW/kg] = area of land use [m^2]
× amount of damage to primary production due to maintenance of unit land area [kgDW/(m^2 ・ year)] × number of years of maintenance of land use for landfill disposal site [year] (2.12-2)

DF_{EINES} [EINES/kg] = area of land use [m^2]
× amount of damage to biodiversity due to alteration of unit land area [EIENS/m^2] (2.12-3)

In this equation, based on (2) above, the area of land use can be calculated as follows:

Area of land use [m^2] = weight-volume conversion factor by type of waste [m^3/kg] × (1 + cover soil [m^3/m^3])
× volume-area conversion rate [m^2/m^3] (2.12-4)

The result of the damage assessment for the impact category of land use was used for the damage amount of land use per unit area. With regard to primary production (2.10.3 (2)), because relatively many final disposal sites are located in mountains, and NPP is low as a result of removal of vegetation from landfill spaces in final disposal sites, a probability density distribution of the damage factor of alteration “forest → construction site” (Table 2.10-13) is applied to the construction of final disposal sites, while a probability density distribution of the damage factor of maintenance of “construction sites” (Table 2.10-12) is applied to the period until discontinuance. A probability density distribution of the damage factor of construction of “final disposal sites” (Table 2.10-15) is applied to biodiversity (2.10.3 (3)). As an example, Figure 2.12-6 shows the process of calculating the primary production damage factor of maintenance of land use for final disposal of bottles and ceramic ware (Equations 2.12-4 and 2.12-2).

(4) Social assets: damage factor of waste

El Serafy’s equation for calculation of user cost (2.11-7) was applied as in the case of the impact category of resource consumption (2.11.3 (7)), and user cost per unit landfill amount of waste was calculated as follows:

$$\text{User cost} = \{1/(1+r)^n\} \times R \qquad (2.12\text{-}5)$$

In this equation, r is the interest rate, n is the remaining capacity of the disposal site, and R is the final disposal price (per volume).

The number of remaining years is the whole landfill capacity divided by annual landfill volume and was calculated for the whole Japan by type of waste (general or industrial) as in the case of the number of remaining years of a disposal site published in the Ministry of the Environment’s White Paper (Ministry of the Environment 2007b). As described above, in Japan, waste is roughly divided into general and industrial waste by law. Although some final waste disposal sites accept both types of waste, permission from final disposal facilities is basically divided between the two. Therefore, a disposal site’s capacity (number of remaining years) for general waste is regarded as different from that for industrial waste. On the other hand, disposal sites for industrial waste are divided into inert-type and controlled-type ones, and burying of some types of waste is prohibited in inert-type disposal sites. However, they are not divided herein and landfill capacities were simply totaled, regardless of type of industrial waste or disposal sites. With regard to general waste especially, although some prefectures have many municipalities with no final disposal sites (Ministry of the Environment 2007b), it is not necessarily transported far. However, this is not taken into consideration. Values published by the Ministry of the Environment (Ministry of the Environment 2005a, 2005b, 2005c) were referred to for whole landfill capacity and annual landfill volume, and extrapolated widely based on changes until FY2003 to make assessment as of FY2005.

It can be thought that there is no nationwide standard unit price for disposal of industrial waste (National Federation of Industrial Waste Management Associations 2003). Herein, the results of a survey on the final disposal commission in the Kanto region (Kanto Regional Council; in the case of inert-type landfill sites, 8,000 yen/m^3 in the prefecture of the lowest limit and 15,000 yen/m^3 in the prefecture of the highest limit; in the case of controlled-type landfill sites, 20,000 yen/m^3 and 35,000 yen/m^3 respectively; excluding public or public-related ones) (Construction Research Institute 2005) were referred to, and a uniform distribution was established between 8,000 to 35,000 yen/ m^3. Because final disposal sites for general waste were usually managed by municipalities, there is no market price.

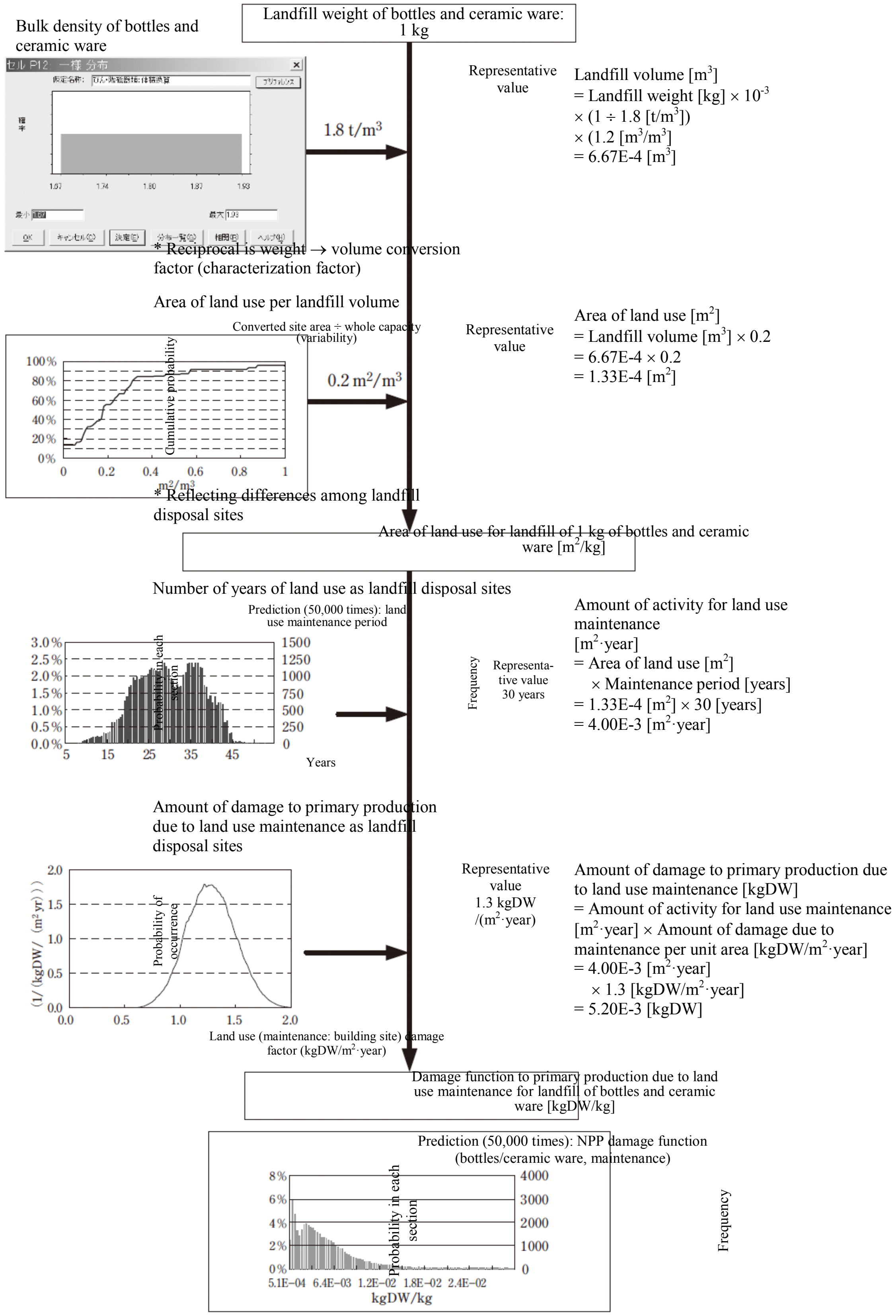

Figure 2.12-6: Example of process of calculating the damage function of waste (landfill of bottles/ceramic ware, land use maintenance)

"Representative value" in the figure is a value shown for illustrating the calculation process and corresponds to the median, etc. of each parameter.

However, it can be thought that if construction, maintenance, and other costs are used, the value of the resource of “disposal space” cannot be reflected in assessment. Because disposal sites for general waste seem to have basically the same structure as controlled-type disposal sites for industrial waste, the same price range as that for controlled-type disposal sites was applied.

A damage factor is basically provided per weight for each type of waste, such as “burnt ash” and “waste plastics.” Therefore, the weight-volume conversion factor and the probability density distribution described in 2.12.3 (2) were applied to convert the user cost per volume into that per type.

(5) Damage factors of waste

This section shows the result of calculation of the damage factor of waste for each area of protection. Under LIME, in addition to specific types, such as “glass and ceramic ware” and “burnt ash,” waste for which information on specific types cannot be gained is called “unknown,” and waste for which landfill volume has been grasped is called “common.” Under LIME 2, the damage factor of the “unknown” type contains uncertainty in the conversion of landfill weight into volume. Because of this, if landfill volume (which is thought to be compressed more than volume at the time of discharge, if waste has large openings) is known, it is desirable to apply the impact assessment factor for the “common” type preferentially. On the other hand, if only the landfill weight of general or industrial waste is known, but the specific type is unknown, it is necessary to apply the “unknown” type.

a. Damage factor to primary production

Figure 2.12-7 shows an example cumulative frequency distribution of damage factors to primary production, and Table 2.12-5 shows example statistical amounts. In addition, because the rank correlation between causes of uncertainty and damage factors is relatively similar irrespective of type of waste or final disposal site for the purpose of the construction of damage functions, Table 2.12-6 shows cases where types of general waste are unknown. The results of assessment of the uncertainty of damage factors contain geographical variability, and the below-described confidence interval indicates the range of estimation of damage factors in the case where waste is buried in different disposal sites. Therefore, it is wrong to interpret that, if the confidence interval of the damage factor for “plastics” greatly overlaps with that for “glass” in the results of assessment of the uncertainty of the damage factors specified under LIME 2, there is no significant difference in the amount of damage between the two when they are buried in the “same” final disposal site.

According to Table 2.12-6, main causes of uncertainty are parameters for calculation of area of land use that accompanies landfill. The variable that has the largest rank correlation factor is the variable that selects the final disposal site at which the waste included in the inventory is buried. This corresponds to the difference in land area necessary for the same landfill volume among land disposal sites.

In addition, because specific types of general waste to be buried are unknown under this classification, the uncertainty in the conversion of landfill weight in the inventory into volume was selected as second place. Third place was a parameter related to the calculation of primary production damage amount per area. The number of years for recovery of primary productivity after discontinuance of a disposal site was selected as the parameter.

Table 2.12-5: Statistical amounts of damage factors of waste landfill (primary production, biodiversity)

Social assets	Primary production				Biodiversity (extinction risk)			
Division	General waste		Industrial waste		General waste		Industrial waste	
Type	Common	Unknown	Common	Unknown	Common	Unknown	Common	Unknown
Unit	kgDW/m^3	kgDW/kg	kgDW/m^3	kgDW/kg	EINES/m^3	EINES/kg	EINES/m^3	EINES/kg
No. of trials	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Average	4.48E+01	5.31E-02	4.48E+01	5.42E-02	3.33E-10	3.94E-13	3.33E-10	4.00E-13
Median	2.85E+01	2.98E-02	2.85E+01	2.95E-02	9.18E-11	9.66E-14	9.18E-11	9.54E-14
Standard error	5.39E+01	7.59E-02	5.39E+01	8.15E-02	9.79E-10	1.33E-12	9.79E-10	1.35E-12
Dispersion	2.90E+03	5.77E-03	2.90E+03	6.64E-03	9.59E-19	1.76E-24	9.59E-19	1.82E-24
Skewness	3.0	4.6	3.0	5.3	10.0	13.6	10.0	14.1
Kurtosis	14.1	36.5	14.1	51.6	169.1	313.9	169.1	346.4
Variation coefficient	1.20	1.43	1.20	1.51	2.94	3.36	2.94	3.38
10% value	6.53E+00	6.75E-03	6.53E+00	6.62E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90% value	9.93E+01	1.19E-01	9.93E+01	1.22E-01	7.50E-10	8.43E-13	7.50E-10	8.57E-13
Average standard error	2.41E-01	3.40E-04	2.41E-01	3.65E-04	4.38E-12	5.93E-15	4.38E-12	6.04E-15

The "unknown type" is applied to cases where landfill weight is known, but the specific type (such as burnt residue) of general or industrial waste is unknown. The "common" type is preferentially applied to cases where landfill volume is known. For details, see the main text of 2.12.3 (5).

Table 2.12-6: Example of rank correlation of causes of uncertainty (general waste (unknown type))

Primary production damage factor (kgDW/kg)			Biodiversity damage factor (EINES/kg)		
#	Variable	Rank correlation	#	Variable	Rank correlation
1	(1) Probability of inventory's correspondence to disposal site	0.59	1	(2) Example of assessment of increased extinction risk#	0.70
2	(1) Weight-volume conversion factor for general waste (unknown type)	-0.37	2	(1) Probability of inventory's correspondence to disposal site	0.34
3	(3) Number of years for recovery of primary productivity after discontinuance of disposal site	0.27	3	(1) Weight-volume conversion factor for general waste (unknown type)	-0.20
4	(1) Volume-area conversion factor (application to area of about 101 to 2,000)	0.18	4	(1) Volume-area conversion factor (application to area of about 101 to 2,000)	0.10

5	(1) Volume-area conversion factor (application to area of about 11 to 100)	0.16	5	(1) Volume-area conversion factor (application to area of about 11 to 100)	0.09
6	(3) NPPp-NPPa (a:building site) (see Equation 2.10-2)	0.11	6	(2) Uncertainty caused by distribution of variability in the number of individuals of *Cephalanthera falcata*	-0.03
7	(1) Intercept of regression equation for conversion of landfill area ranking to volume (landfill area: about 11 to 100)	0.05	7	(2) Number of individuals of *Cephalanthera falcate* at a point of EIA example	0.03
8	(1) Number of years until discontinuance after closure of disposal site	0.04	8	(1) Intercept of regression equation for conversion of landfill area ranking to volume (landfill area: about 11 to 100)	0.02
9	(1) Number of operating years of disposal site (mid-size)	0.04	9	(2) Parameter C of regression equation for estimation of number of years until extinction of species	-0.02

- Top nine variables were selected for each factor.
- The factors with (1) are causes of uncertainty in estimation of land area per final disposal amount. “Probability of inventory’s correspondence to disposal site” is geographical variability that assumes the disposal site where the final disposal amount specified in the inventory is buried for the purpose of calculation of area of land alteration and corresponds to difference by size of disposal site (area ranking). “Volume-area conversion factor” indicates a change in examples of disposal sites with similar size.
- The causes with (2) are parameters for estimation of biodiversity damage amount per land area. “Example of assessment of increased extinction risk#” corresponds to difference in examples of the degree of increased extinction risk per unit area caused by land alteration for construction of a final disposal site. For details of all the parameters, see Section 2.10.
- The cause with (3) are parameters for estimation of primary production damage amount per land area. For details, see Section 2.10.

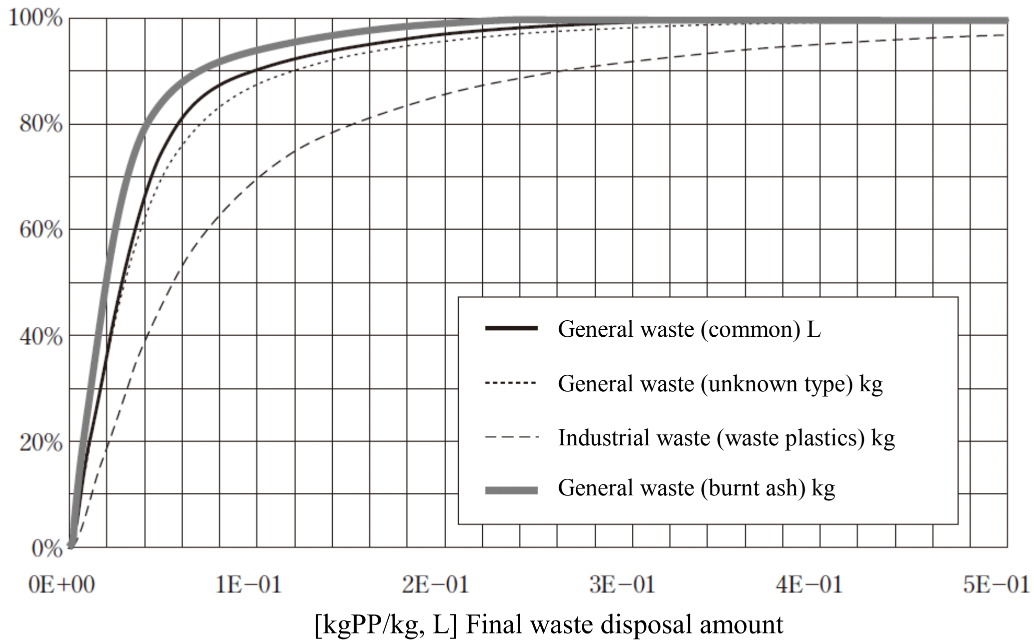

Figure 2.12-7: Cumulative probability density distribution of primary production damage factors

The “unknown type” is applied to cases where landfill weight is known, but the specific type (such as burnt residue) of general or industrial waste is unknown. The “common” type is preferentially applied to cases where landfill volume is known. For details, see the main text of 2.12.3 (5).

Figure 2.12-8 shows the result of comparison between the damage factors under LIME 1 and those under LIME 2. Some types of waste relatively changed as a result of a review of the conversion factor from landfill weight to volume. In addition, the weight-volume conversion factor is the only parameter whose value changes according to type of waste. The variation coefficients of the damage factors are almost the same irrespective of type of waste. In other words, as a damage factor becomes larger, the width of the confidence interval tends to become larger.

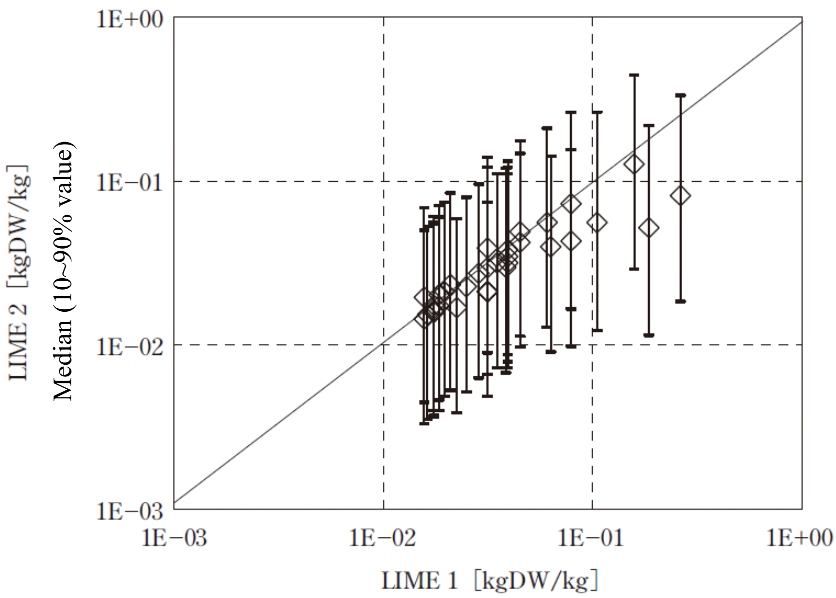

Figure: 2.12-8: Comparison between LIME 1 and LIME 2 (primary production damage factor)

b. Damage factors to biodiversity

Figure 2.12-9 shows an example of the cumulative frequency distribution of biodiversity damage factors, and Table 2.12-5 shows an example of statistical amounts. Table 2.12-6 shows the rank correlation between causes of uncertainty and damage factors as in the case of primary production.

Unlike the case of primary production, the main cause of uncertainty is a change in the increased extinction risk per unit area (UAR) that accompanies land alteration for construction of a final disposal site. As shown in 2.10.3 (3) (Figure 2.10-13), because UAR greatly differs among examples of construction of a final disposal site, and because all the final disposal amounts entered in the inventory are regarded as having been buried in a single disposal site that cannot be identified from among many disposal sites in Japan, it can be understood that the impact assessment result of multiplication of the inventory by the damage factor has a large width.

Figure 2.12-10 shows the result of comparison between the damage factors under LIME 1 and those under LIME 2. Changes in the trends between LIME 1 and LIME 2 are the same as in the case of primary production.

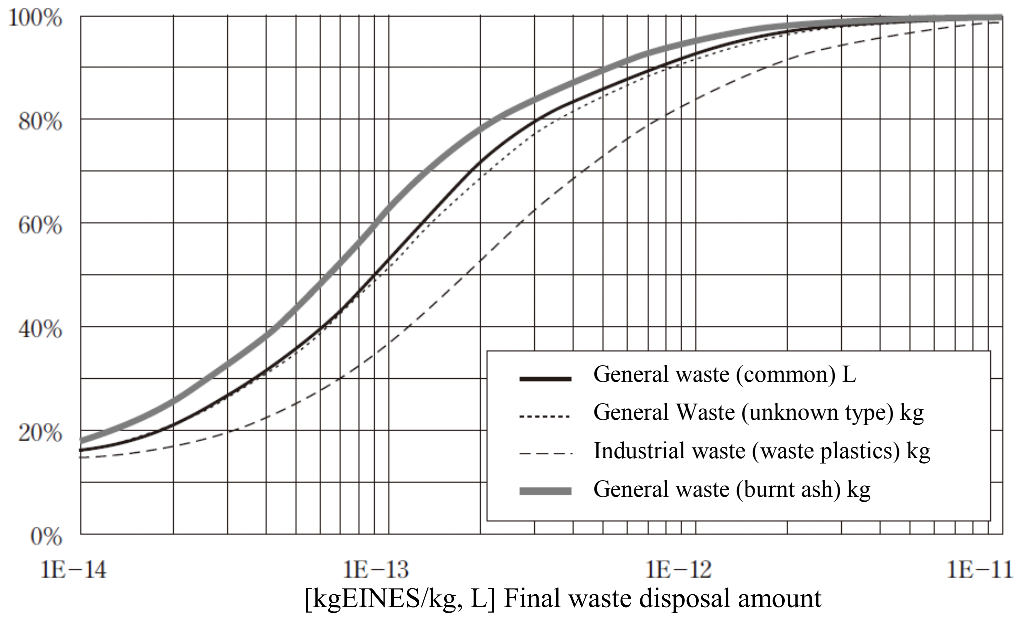

Figure 2.12-9: Cumulative probability density distribution of damage factors to biodiversity

The "unknown type" is applied to cases where landfill weight is known, but the specific type (such as burnt residue) of general or industrial waste is unknown. The "common" type is preferentially applied to cases where landfill volume is known. For details, see the main text of 2.12.3 (5).

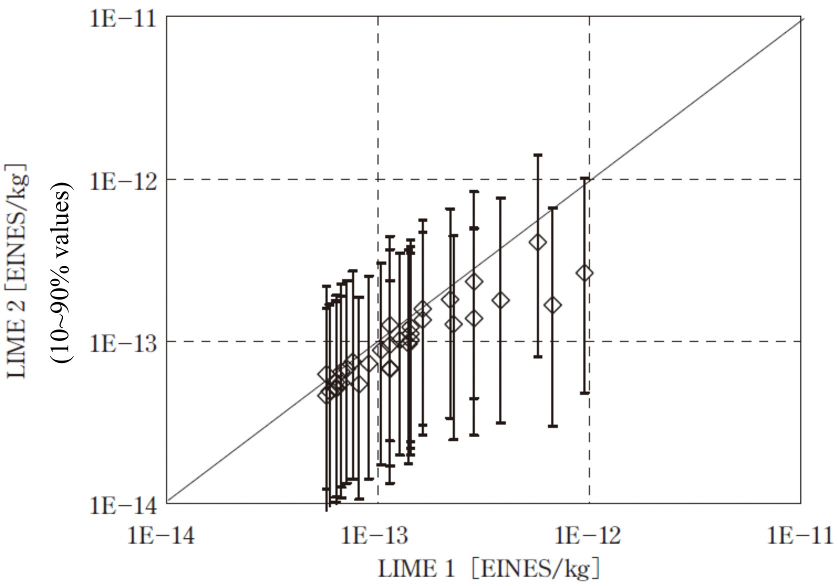

Figure 2.12-10: Comparison between LIME 1 and LIME 2 (damage factors to biodiversity)

c. Damage factors to social assets

Table 2.12-7 shows the gained statistical amounts, and Figure 2.12-11 shows the frequency distribution. As described above, the damage assessment of waste landfill under LIME is based on damage per volume, which has been converted into damage per weight. Therefore, if the type of waste to be buried is unknown, because the conversion from weight to volume has a certain range, the histogram for the damage factor per weight is horizontally wider than that for the damage factor per volume.

Table 2.12-7: Statistical amounts of user costs of waste landfill

Division	General waste		Industrial waste	
Type	Common	Unknown	Common	Unknown
Unit	Yen/m^3	Yen/kg	Yen/m^3	Yen/kg
No. of trials	50,000	50,000	50,000	50,000
Average	1.77E+04	2.50E+01	1.55E+04	2.26E+01
Median	1.76E+04	2.17E+01	1.52E+04	1.83E+01
Standard error	2.90E+03	1.27E+01	6.51E+03	1.77E+01
Dispersion	8.42E+06	1.61E+02	4.24E+07	3.13E+02
Variation coefficient	0.16	0.51	0.42	0.78
10% value	1.38E+04	1.32E+01	7.21E+03	7.85E+00
90% value	2.16E+04	4.08E+01	2.46E+04	4.08E+01
Average standard error	1.30E+01	5.68E-02	2.91E+01	7.91E-02

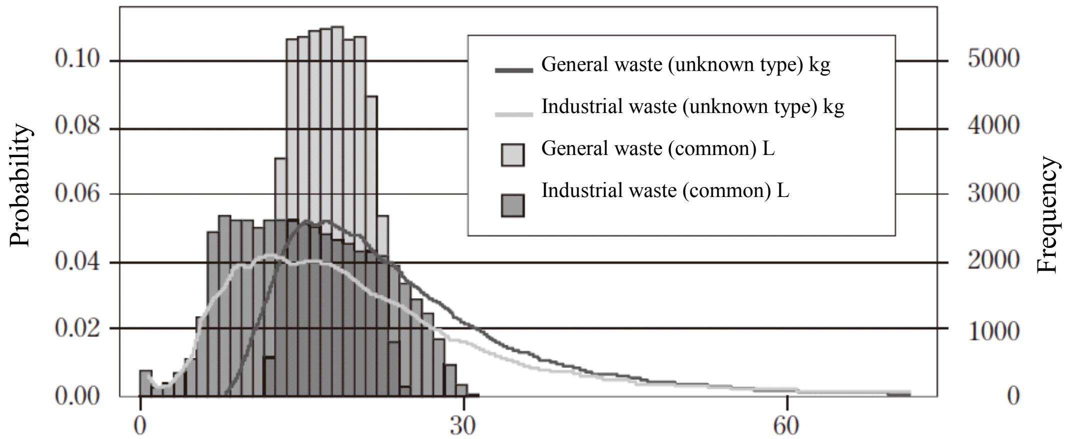

Figure 2.12-11: Histogram of user costs of final waste disposal

The "unknown type" is applied to cases where landfill weight is known, but the specific type (such as burnt residue) of general or industrial waste is unknown. The "common" type is preferentially applied to cases where landfill volume is known. For details, see the main text of 2.12.3 (5).

Table 2.12-8: Rank correlation of user costs of final waste disposal

Industrial waste (unknown type)		General waste (unknown type)	
Variable	Rank correlation	Variable	Rank correlation
Weight-volume conversion factor of industrial waste (unknown type)	-0.63	Weight-volume conversion factor of industrial waste (unknown type)	-0.91
Final disposal price of industrial waste	0.63	Final disposal price of industrial waste (controlled-type disposal site)	0.37
Final disposal amount of industrial waste in Japan	0.27	Remaining capacity of final disposal sites for general waste in Japan	-0.09
Remaining capacity of final disposal sites for industrial waste in Japan	-0.04	Final disposal amount of general waste in Japan	0.05

This table only shows the top four variables.

The distribution for industrial waste is wider than that for general waste because, as shown in the rank correlation (Table 2.12-8), the range of disposal prices was set up by mixing of inert-type disposal sites and controlled-type ones by disposal prices and because uncertainty was large in the estimation of the landfill disposal amount in 2005, when the amount was sharply decreasing.

2.12.4 Procedures for impact assessment of waste

Concrete procedures for characterization and damage assessment of waste are as follows. It is necessary to note that impact assessment of waste only covers the final disposal amount in the inventory of the waste species *X*, *Inv* (*X*). In other words, the amount of waste reduced or made into resources through intermediate treatment after the generation/discharge of waste (after disposal of LCA-assessed products after use) is not included. Of course, if treatment residue is buried, the amount of the residue is included. For the treatment of construction waste soil, which is excluded from the types of waste defined by law, see Column 2.12-1 also.

Column 2.12-1:

Land use that accompanies the disposal of construction waste soil

Although construction waste soil does not fall under the category of waste under the existing law, it is generated and disposed of in large quantities (Aoyama 1993). In addition, according to the result of an LCIA case study about buildings (Ii et al. 2002), it was found that construction waste soil can have important influence on LCIA that takes into consideration the impact on land use.

The purposes and disposal sites of construction waste soil were not necessarily clear in the latest construction byproduct statistical materials as of the survey. Under LIME, the percentage distribution of purposes and disposal sites were grasped from actual values in FY1995 (Committee for the Promotion of Recycling of Construction Byproduct 1997). Of the purposes, inter-construction use, recycling facilities, raising of farmland, landfill of vacant lots after mining, and cover soil of waste disposal sites were thought to lead to the generation of new land use, and marine landfill, valley landfill, and inland water landfill were connected to the impact category of land use. However, according to reported cases of landfill of vacant lots after mining (Sakuma 2002), it is necessary to consider further how to incorporate such landfill into the assessment method.

With regard to marine landfill, the ratio between landfill volume and area was calculated to be 0.08 m^2/m^3 after the collection and arrangement of materials related to the marine landfill projects about which the Ministry of the Environment issued opinions in the past in view that the area of landfill exceeded 50 ha. In addition, with regard to valley and inland water landfill, the ratio was assumed to be the same as the value for waste disposal sites calculated in 2.12.3 (2).

Based on the above-described results, the area of land use per 1 m^3 of waste soil taken out was calculated to be 0.05 m^2/m^3 as the default value if the final disposal method and the amount of disposal of generated waste soil are unknown.

In addition, the landfill disposal standards prohibit the landfill of waste acid and alkali and provide that waste oil (excluding tar pitch) should be burnt by the use of incineration equipment. Therefore, if the amount of such waste is included in the amount of disposal in the inventory, it can be said that retroaction is insufficient for impact assessment. It is also necessary to note that although decomposed matters (such as organic sludge) require cover soil unless they are burnt to 15% or less by ignition loss, cover soil that accompanies the landfill of industrial waste is uniformly included in the assessment factors provided by LIME concerning all types.

With regard to characterization, landfill weights are converted to volumes after landfill according to type of waste by Equation 2.12-6 to calculate the category index *CI* from the viewpoint of alteration of nature due to landfill. If volumes after landfill are already calculated during the inventory, it is all right to total them simply.

$$CI^{Landfill} = \sum_{X} CF^{Landfill}(X) \times Inv(X) \tag{2.12-6}$$

In addition, the index for the endpoint approach – that is, the damage index *DI* (*safe*) – can be gained from *Inv* (*X*) of each type of waste and the damage factor *DF* (*Safe, X*) for each area of protection *Safe*. This enables damage assessment of biodiversity, primary production, and social assets. With regard to common areas of protection, it is possible to make comparison and integration with the amounts of damage generated through different impact categories.

$$DI(Safe) = \sum_{X} DF^{Landfill}(Safe, X) \cdot Inv(X) \tag{2.12-7}$$

The factor $IF^{Landfill}$ (*X*), into which the impact on biodiversity, primary production, and social assets has been integrated, is used for integration. The single index *SI* can be gained from each waste's *Inv* (*X*) and the integration factor $IF^{Landfill}$ (*X*). The result can be directly compared with or added to assessment results in other impact categories.

$$SI = \sum_{X} \left(IF^{Landfill}(X) \times Inv(X) \right) \tag{2.12-8}$$

The characterization factor $CF^{Landfill}$ (*X*) is listed in Appendix A1, the damage factor $DF^{Landfill}$ (*Safe, X*) is listed in Appendix A2, and the integration factor $IF^{Landfill}$ (*X*) is listed in Appendix A3.

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2.13 Noise (Road Traffic Noise)

- Although traffic noise – especially, road traffic noise – is important all over Japan, it was an environmental problem that was not considered to be an impact category (no damage function was developed) under LIME 1.
- Under LIME 2, the damage function of road traffic noise in Japan was developed and "noise" was added as a new impact category.

2.13.1 What phenomenon is the environmental impact of noise?

(1) Causal relationship between noise and environmental impact

Noise is generally defined as undesirable sound. Meanwhile, sound is closely connected with everyday life as conversation, music, and other means to convey information. This is one of the causes that makes the noise problem complicated (Yamamoto et al. 1988). The types of noise covered by this section, such as road noise, aircraft noise, Shinkansen railway noise, factory noise, and construction noise, are regarded by almost all people as loud and unpleasant at any place (Kabuto 2005). Figure 2.13-1 shows the pathway of the environmental impact of noise.

The energy that sound generates per second is expressed as watt (W). The energy of sound that passes a unit area every second when spreading through the air [W/m^2] is called sound intensity. A change in the atmospheric pressure due to sound is called sound pressure, and sound intensity is proportionate to the square of sound pressure.

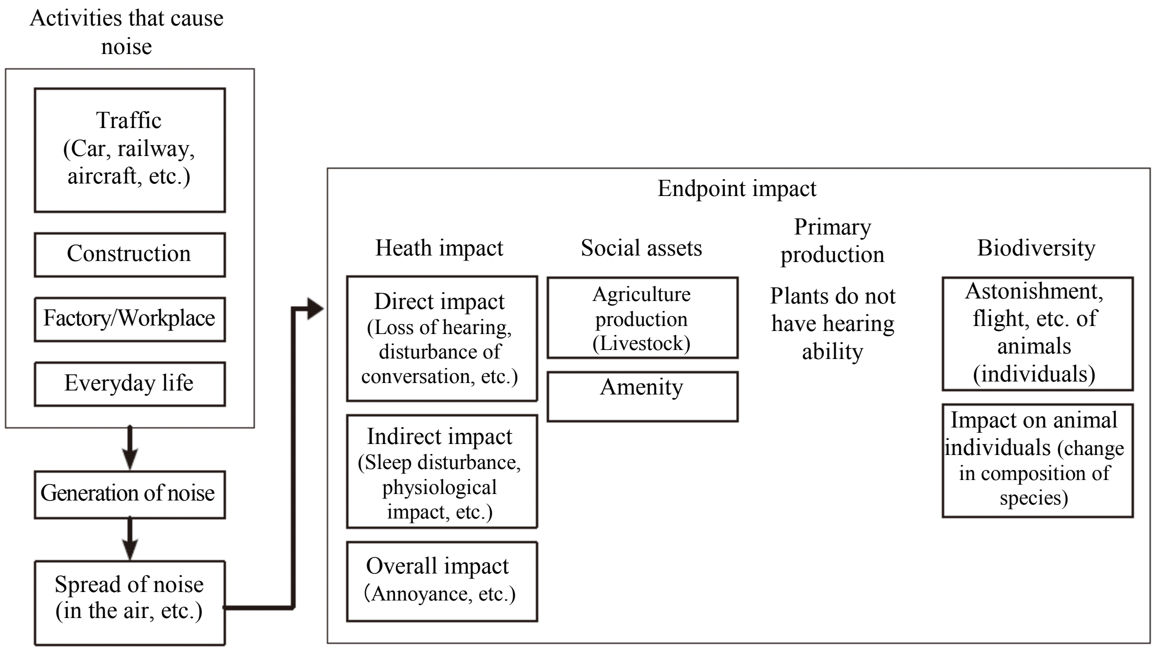

Figure -2.13-1: Causal relationship between noise and environmental impact

It is known that human beings' sensibility (response) to sound intensity is proportionate to relative changes in sound intensity (stimulus) (Weber–Fechner law: $\Delta E = \Delta S/S$). Because of this, the magnitude of sense to sound is proportionate to the logarithm of sound intensity. Therefore, the level of sound pressure or intensity is often expressed with a logarithm based on the threshold of hearing, by the use of the unit of dB (decibel). Sound output also is expressed by logarithms (acoustic power level, PWL).

Moreover, if the sound pressure level is the same, loudness for people changes if frequency differs (Figure 2.13-2). Therefore, noise intensity (noise level, L_A) is measured after adding some weighting (usually, the weighting called A-weighting) to the sound pressure level. Although in the past a noise level was expressed with "phon" or "dB (A)," it is now expressed uniformly with "dB" under the Measurement Act and the like. Notwithstanding differences in units, values are the same. Usually, the level of sound pressure is equal to the level of sound intensity.

Japan's Third Basic Environmental Plan (Ministry of the Environment 2006), which was approved by the Cabinet in April 2006, dealt with traffic noise in a part concerning the current situation and issues of urban air pollution and states that "the situation of noise damage in surrounding areas due to traffic is generally severe. In areas surrounding highways in particular, the environmental standards concerning automobile noise have continued to be hard to achieve. With regard to the Shinkansen railways also, there are many portions where the environmental standards have still not been satisfied."

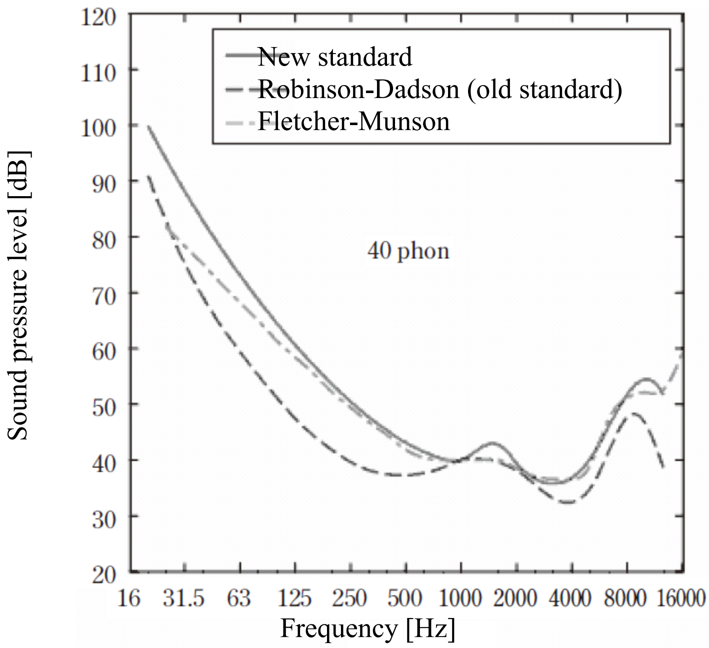

Figure 2.13-2: Examples of equal loudness level contours (40 phon)

- A contour that joins levels of sound intensity so that sensuous loudness can become the same even if there are changes in the frequency of pure sound (sound with a single frequency element) is called an equal-loudness level contour. The dB level that has the same loudness at the frequency of 1 kHz is expressed with the unit of phon. The above figure (40 phon) shows contours indicating the same loudness as pure sound with a sound pressure level of 40 dB at the frequency of 1 kHz.
- Under Japan's leadership, the international standard was completely revised by a new equal-loudness level contour based on the results of research by an international joint research group that provided data that accounted for 40% of the total (ISO 226: 2003). As a result of

the research, it became clear that A-weighting (based on Fletcher-Munson's equal-loudness contour with 40 phon), which is used for noise level, corresponds well to the new equal-loudness level contour.

Source: Citation from and summary of the press release by the National Institute of Advanced Industrial Science and Technology (on October 22, 2003) entitled "Entire Revision of the International Standard ISO 226 concerning Equal Loudness Contours"

(2) Endpoints of the environmental impact of noise

There are various impacts of noise on human beings. Osada (2001) roughly classified them into the following three categories: (1) sensual influence, disturbance of conversation, and loss of hearing ability as direct and peculiar impacts; (2) emotional influence, disturbance of sleep/rest, disturbance of work, and physical influence (circulatory, digestive, and other systems) as indirect and non-peculiar impacts (impacts of stress not peculiar to noise; and (3) annoyance (general sense of damage) and behavioral reaction as general impacts (Figures 2.13-3 and 2.13-4).

Japan's environmental standards for noise (1998) set up standard values at equivalent noise level (temporal average of noise energy) according to purpose of land use, taking into consideration the degree of annoyance according to noise level, considering disturbance of sleep and conversation as endpoints and distinguishing between nighttime and daytime. The standard values for areas facing roads are different from those for the other areas (general areas), and notifications about the environmental standards for aircraft noise and Shinkansen railway noise have been given separately (Table 2.13-1).

Subsequently, the World Health Organization (WHO) internationally published guidelines on noise (Berglund et al. 1999). To prevent disturbance of nighttime sleep, the guidelines fix the indoor guideline value at 30 dB and the outdoor guideline value for a bedroom with the window opened at 45 dB. During the daytime, it fixes the indoor guideline value at 35 dB from the viewpoint of disturbance of conversation and fixed the outdoor guideline value for residential districts at 50 to 55 dB according to the degree of annoyance (although the guidelines show the maximum noise level, only equivalent noise levels are quoted herein in harmony with the environmental standards in Japan).

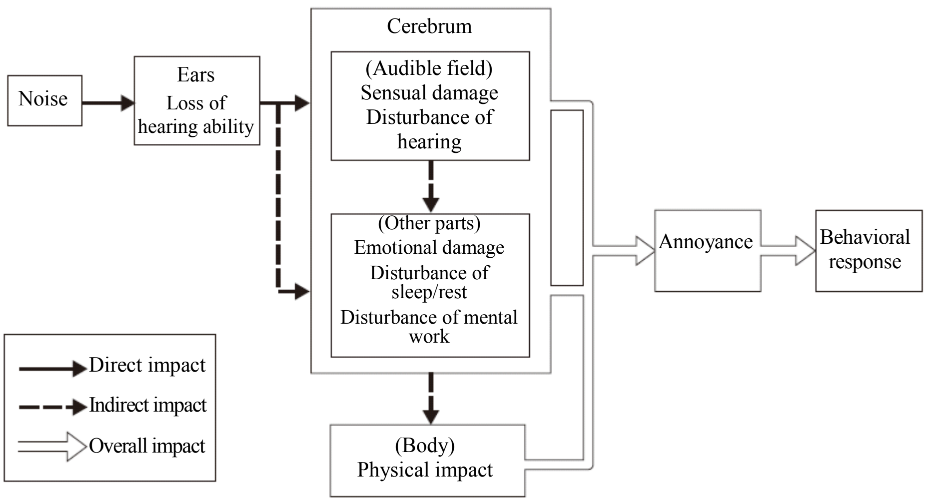

Figure 2.13-3: How impact is caused by noise

Source: Osada (2001)

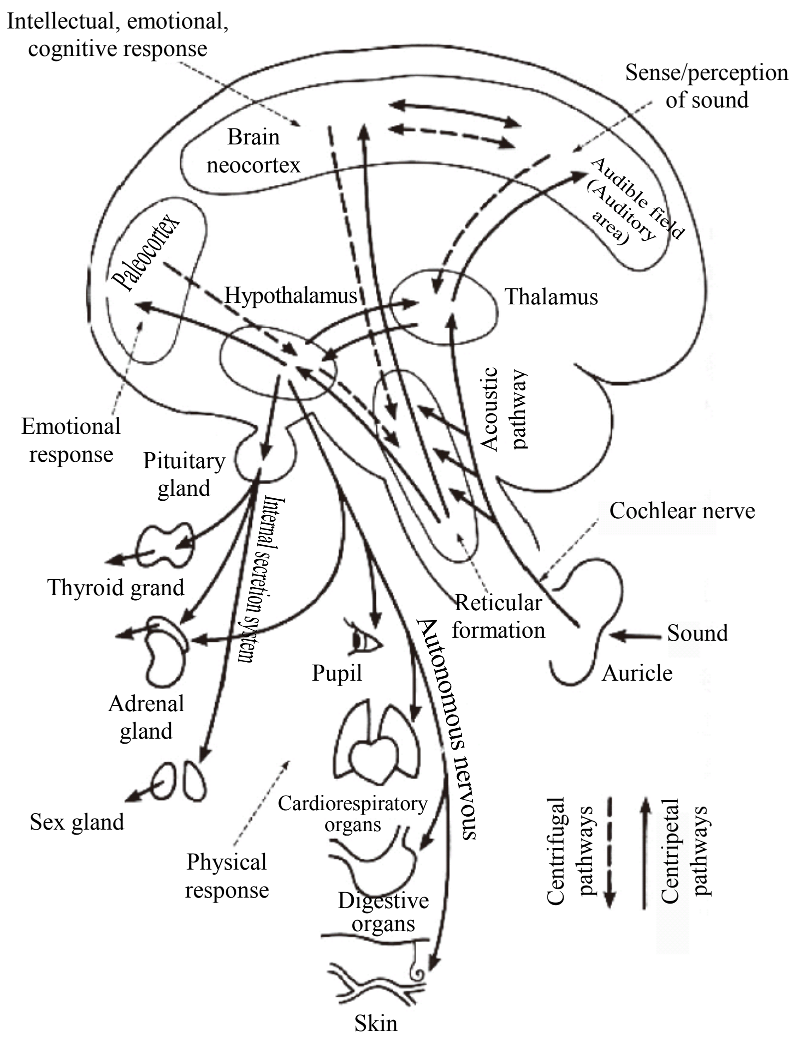

Figure 2.13-4: Pathways of mental and physical impacts of noise

Source: Some words were added to Osada (2001).

Table 2.13-1: Environmental standards for noise in Japan (unit: dB)

<table>
<tr><th rowspan="2">Time zone†
Type of area</th><th colspan="2">General area</th><th colspan="2">Area facing road*</th><th colspan="2">Area near highway *</th></tr>
<tr><th>Day</th><th>Night</th><th>Day</th><th>Night</th><th>Day</th><th>Night</th></tr>
<tr><td>AA (area requiring quiet)</td><td>≦50</td><td>≦40</td><td></td><td></td><td></td><td></td></tr>
<tr><td>A (exclusively residential area)</td><td rowspan="2">≦55</td><td rowspan="2">≦45</td><td>≦60</td><td>≦55</td><td rowspan="3">≦70</td><td rowspan="3">≦65</td></tr>
<tr><td>B (mainly residential area)</td><td rowspan="2">≦65</td><td rowspan="2">≦60</td></tr>
<tr><td>C (area where houses are mixed with commerce/industry)</td><td>≦60</td><td>≦50</td></tr>
</table>

† Time zone: Day = 6 a.m. to 10 p.m.; Night = 10 p.m. to 6 a.m. of the next day

* An area facing a road is an area where road traffic noise governs. A highway is a national expressway, an ordinary national road, a prefectural road, or a section of a municipal road with four or more lanes. An area near a highway is within 15 m (up to two lanes) or 20 m (two or more lanes) (the Director-General of the Air Quality Bureau of the Ministry of the Environment's notification to each prefectural governor entitled "Revision of the Environmental Standards for Noise" (September 30, 1998, Kantaiki No. 257)).

• These values have been set based on indoor guideline values under the following procedure (Central

Environment Council 1998): environmental standards in an area falling under A (exclusively residential) that faces a road (example: nighttime): indoor guideline value for impact on sleep [35 dB (general area), 40 dB (area facing road)] + 10 dB (building soundproof performance with window opened) + 5 dB (further correction for an exclusively residential area that faces a road) = 55 dB (however, indoor guideline value + 25 dB for a space near a highway). The indoor guideline value for impact on conversation is 45 dB.
Source: "Environmental Standards for Noise" (the Ministry of the Environment's Notice No. 64 of September 30, 1998)

Moreover, the guidelines mention physical health impact, although it is not specified as a guideline value. For example, the guidelines point out that the impact of long-term exposure to aircraft or road traffic noise of 65 to 70 dB at a 24-hour equivalent noise level on the circulatory system has been proved and that although an increase in the risk of suffering ischemic heart disease is small, the exposure population is large. According to a recent review (Babisch 2006), although epidemiological research on the health impact of traffic noise has been carried out mainly in Europe, in Japan also a large-scale study was carried out around the Kadena and Futenma airfields by Okinawa Prefecture (1999). According to the results, an increase in the ratio of babies born with a substandard weight, a decline in schoolchildren's long-term memory, and an increase in the ratio of people with mental or physical disease (which was found by a Todai Health Index (THT) survey) were detected at significant levels.

The auditory pathway from the external auditory canal to the auditory area of the brain cortex via the auditory nerve is similar among mammals. According to various reports on the impact of sound on laboratory animals, although in many cases a short-term load was imposed, the impact of sound on animals tended to depend on the amount of load energy (Honma 1982). Concretely, environmental impacts include not only animals' astonishment at sudden noise of construction but also flight from the point of impact, which may influence foraging and breeding. Forman & Alexander (1998) describes that, with regard to the ecological impact of roads and vehicles on a group of individuals, the impact of traffic disturbance is far greater than that of direct road kill (traffic accidents) and traffic noise would be the most important factor. They also report that, in forests and prairies near highways, the growth density of birds is low and the richness of species has been decreasing, and introduce oscines (songbirds) sensitive to a considerably low noise level. In addition, it has been reported that, although, unlike wildlife, livestock cannot escape, cow milking was influenced in some cases (Mito Construction Office of Japan Highway Public Corporation 2000).

2.13.2 Characterization of noise

(1) Characterization factor of noise under the existing LCA method

With regard to the geographical and temporal characteristics of noise impact, for example, if a noise from a machine in a factory is so loud that it is impossible to make conversation near the machine, it is quiet around the border of the factory premises, and noise is not accumulated in the air like carbon dioxide. In addition, from the viewpoint of the amount of environmental load, the "noise level" to be measured under regulations is like the density of pollutants in the air in the case of air pollution – that is, not the quantity of flow but the quantity of state. Because of this, it is hard to put noise impact in harmony with the flow accumulation method of LCA.

Table 2.13-2 shows the development of treatment of noise under LCIA so far. SETAC's early report on LCIA (Fava et al. 1993) described the following points concerning noise problems in life cycle impact assessment:

- The present LCA cases do not usually include noise data.
- Although noise is one of the important environmental problems, the impact is local. Moreover, measures are basically taken at each site (such as factory noise).
- It is hard to imagine any index that can significantly indicate all the processes related to life cycle.
- Traffic noise (which has an area extent) is an exception. If these are possible, they should be included in the objects of LCA.

Table 2.13-2: Development of treatment of noise by LCA (examples of research cases)

Year	Case
1992	CML Guide (Heijungs et al. 1992): Sound energy (Pa^2s) was recommended for characterization.
1993	SETAC LCIA Report (Fava et al. 1993): See the main text.
1999	EPS2000 method (Steen 1999): "Nuisance" was included in health impact and was defined (it was not WTP of noise itself).
1999, 2002	Müller-Wenk (1999, 2002): They suggested a damage assessment method for road traffic noise, and published the results of assessment conducted in Switzerland (University Research Institute Report (1999), Swiss Agency for the Environment (2002)).
2001	CML Guide (Guinée et al. 2002): Pa^2s continued to be recommended for characterization. Using Müller-Wenk (1999) as the starting point, they showed expectations for assessment of impact on human health and other endpoints.
2002	SETAC 2nd WG on LCIA Report (Udo de Haes et al. 2002): This report mentioned EPS only briefly.
2003	UNEP/SETAC Life Cycle Initiative "LCIA Definition Study" Report (Jolliet et al. 2003): Traffic noise was positioned as a midpoint category.
2003	JEPIX method: "EIP/noise km" was presented by the Distance To Target method (traffic volume and environmental standards) (Miyazaki et al. 2003).
2004	Attention was paid to Müller-Wenk (2002) in a review by Pennington et al. (2004).
2004	EDIP2003 method: Although a report for researchers (Potting&Hauschild 2004) reviewed noise, guidelines for practical persons (Hauschild&Potting 2005) did not mention it. * EDIP97 mentioned occupational exposure.
2006	Arjen Meijer (2006): Road traffic noise was included in a housing LCA case study (damage assessment).

- Noise is not included in the other LICA method systems not mentioned in this table, such as Eco-indicator 99, IMPACT 2002+, TRACI, and LIME 1.
- Of the LCIA method systems mentioned in this table, EPS and EDIP 2003 also did not provide any practically assessable method.

While no suggestion was given of an operational assessment method that can be said to be available practically, Müller-Wenk suggested a damage-calculating-type assessment method in 1999 and 2002. As described in CML Guide (Guinée et al. 2002) and UNEP/SETAC Life Cycle Initiative's LCIA Definition Study Report (Jolliet et al. 2003) thereafter, the method has drawn attention as a method that enables impact assessment of noise under LCA. The frameworks and some important parameters of the damage function developed under LIME 2 also are based on Müller-Wenk's research.

So far, the LCIA method systems that include noise in the impact categories have been extremely limited in effect, and the number of assessment cases by the systems seems small. However, some recent LCA case studies have dealt with noise impact. In LCA of houses, Meijer (2006) assessed noise in addition to air pollutants during research for including road traffic damage to human health in the assessment.

(2) Characterization factor of noise under LIME

Sound energy has been suggested as an index for characterization. In addition, JEPIX (Miyazaki et al. 2003) has introduced a virtual unit called “noise-kilometer.” This is based on the Swiss Agency for the Environment’s material and is the total of passenger cars’ annual mileage, and trucks and other large vehicles’ annual mileage multiplied tenfold on the assumption that the noise of ten passenger cars is equivalent to the noise of one truck. This is similar to sound energy in that attention is paid to the energy of generated noise.

Under LIME 2, as described in 2.13.3 below, a damage function for calculation of health impact (DALY index as in the case of the other impact categories) was developed based on vehicle-km in Japan, assuming disturbance of sleep and conversation as endpoints. From the viewpoint of characterization, it is important to give priority to the reduction of uncertainty through comparison among the impact categories rather than the comparability with the other impact categories and to select a midpoint index that can comprehensively and conceptually connect with as many endpoints as possible. In addition, under an LCIA system, it is desirable that the characterization factor should be consistent with the damage factor.

Based on what has been described above, under LIME 2, the energy of generated noise was used as the midpoint index, a part of the damage factor was picked out, and the noise energy to vehicles’ mileage volume [J/vehicle-km] was suggested as the characterization factor.

For example, the characterization factor for small vehicles was calculated. First, the running time was assumed as the reciprocal of driving speed, and the noise energy generated per 1 vehicle-km was calculated for each road section as follows:

Noise power of a small vehicle [W] × running time [seconds/km] (エラー！指定したスタイルは使われていません。.1)

Next, the weighted average of the result was calculated by the frequency of appearance in the target time zone (daytime, nighttime, or 24-hour) for each road section to find the characterization factor. The frequency of appearance was made proportionate to the current traffic volume [vehicle-km] (of small vehicles, for example) for each road section. Although the noise power becomes larger with faster running speed, because the running time for unit distance becomes shorter, the difference in noise energy caused by the difference in running speed becomes smaller. Because the model of noise power used herein in particular makes the noise energy stable irrespective of speed in an unsteady running section, the value does not change according to the frequency of appearance (on what road vehicles are running). That is, this characterization factor is hardly reflected in geographical variability (difference in the roadside situation).

Table 2.13-3 shows the calculated characterization factor. Large vehicles’ characterization factor is about 7 times as high as passenger cars’, a little smaller than 10 times in JEPIX. The reason for this seems to be a difference between Japan and Switzerland in the passenger

cars and large vehicles (trucks) assumed in their noise power models.
Because noise power is sound power weighted with the above-described A-weighting through frequency, strictly speaking, the characterization factor's midpoint index is different from the sound energy suggested by CML, but seems consistent with JEPIX's "noise-kilometer" in this point.

To make it closer to the damage factor, it is possible to carry out an assessment by the use of the increment in the roadside noise level (in the case of air pollution, the increment in the density of air pollutants) or the amount of noise energy to which a human body is exposed (intake fraction) as the next step to the generation of noise energy. In the former case, if the ratio of large vehicles' assessment factor to small vehicles' is calculated, the result is 3.9 times in the daytime and 2.7 times in the night time. Therefore, the difference in vehicle type becomes a little narrower than in the case of noise energy (4.9 times). On the other hand, because, unlike the increment in the noise level or the damage factor, the characterization factor can hardly express the difference in environmental impact between the daytime and the nighttime, it is inappropriate to use the characterization factor for comparing scenarios with different driving time zones. Because of this, information on the characterization factor for each time zone was not disclosed.

The used model parameters, such as the equation for calculating noise power and data on speed and traffic volume, are the same as those for the damage function. For details, see 2.13.3 below.

Table 2.13-3: Characterization factor of vehicle noise

Time zone	Driving category, vehicle type	Characterization factor [J/vehicle km]
Unknown	Vehicle noise (small vehicle)	0.65
Unknown	Vehicle noise (small vehicle; passenger car)	0.61
Unknown	Vehicle noise (small vehicle; small freight car)	0.80
Unknown	Vehicle noise (large vehicle)	3.21
Unknown	Vehicle noise (large vehicle; midsize car)	2.17
Unknown	Vehicle noise (large vehicle; large car)	4.23
Unknown	Vehicle noise (unknown type)	1.14

- Vehicle type is based on ASJ RTN-Model 2003 (Road Traffic Noise Research Committee, Acoustic Society of Japan 2004). Concrete definitions are as follows:
- A passenger car is a vehicle whose number plates starts with 3, 5, 7, or 4 (van) and whose capacity is up to 10.
- A small vehicle has a number plate starting with 4 (excluding van) or 6, exceeds 50 cc in displacement volume, and is up to 4.7 m in length.
- A midsize vehicle is a freight car (usually, two-axle) whose number plate starts with 1 or 2 and whose length exceeds 4.7 m, excluding a large vehicle, or a midsize bus with a capacity of 11 to 29.
- A large vehicle a freight car (usually, three-axle) with a number plate starting with 1 or 2 (large plate) or 9 or 0 and with a gross vehicle weight of 8 or more tons or a maximum load capacity of 5 or more tons, a large bus with a capacity of 30 or more, or a large special vehicle.
- Special-purpose vehicles with a classification number starting with 8 are classified according to the actual condition.
- Mini vehicles are included in vehicles with a classification number standing with 4 or 5.
- Two-wheel automobiles and motorized bicycles are included in small freight cars.

2.13.3 Damage assessment of noise

(1) Basic policy for calculation of damage factor and assessment of uncertainty

Taking application to LCA into consideration, Müller-Wenk (1999, 2002, 2004) showed a framework for the damage function of road traffic noise by DALY and calculated the assessment factor in the case of Switzerland. Under LIME 2, based on this framework, the calculation procedure was improved and damage function was established based on data and models in Japan.

Figure 2.13.5 shows the structure of the damage function. Vehicle-kilometrage by vehicle type (large or small vehicle) and time zone (daytime or nighttime) was assumed to be the inventory data item that serves as the starting point for the damage function. Although Müller-Wenk also used such classification into four in total, in the impact assessment category of noise (environmental assessment, etc.) also, it is usual to divide vehicles into large and small ones, which differ from each other in noise power level, and make a daytime assessment and a nighttime assessment separately.

Table 2.13-4: Category endpoints of noise and objects of calculation of damage function

Area of protection	Category endpoint		Object of calculation of damage function	
Human health	Direct specific impact	Sensual impact	×	The impact was judged to be very slight as health damage by DALY index.
		Hearing disturbance	○	Conversation disturbance was selected as a representative endpoint.
		Loss of hearing ability	×	It was thought that usual road traffic noise does not have sufficiently serious impact to be assessed by DALY index.
	Indirect unspecific impact	Emotional impact	×	Qualitative assessment is difficult.
		Sleep/rest disturbance	○	Sleep disturbance was selected as a representative endpoint.
		Work disturbance	×	Qualitative assessment is difficult.
		Physical impact (Physiological impact)	×	Qualitative assessment is difficult. In a past case (de Hollander 1999), although grounds for calculation were not confirmed, DALY impact of noise on ischemia may be relatively small.
	Overall impact	Annoyance	×	Secondary impact
		Behavioral response	×	
Social assets†	Amenity	Loss of quietness	×	Qualitative assessment is difficult.
	Impact on livestock	Decrease in amount of milking, etc.	×	Qualitative assessment is difficult.
Biodiversity	Impact on wildlife	Astonishment, flight,etc.	×	Qualitative assessment is difficult.

† With regard to external diseconomy assessment of noise, many cases were assessed by the hedonic approach. The hedonic approach measures the amount of damage as a decline in the asset value of land. However, this decline can be thought to be final result of various impacts on human health, etc. (however, it is possible to think that there is no perceived impact). Because of this, it was not included in the category endpoints herein, in order to prevent double accounting.

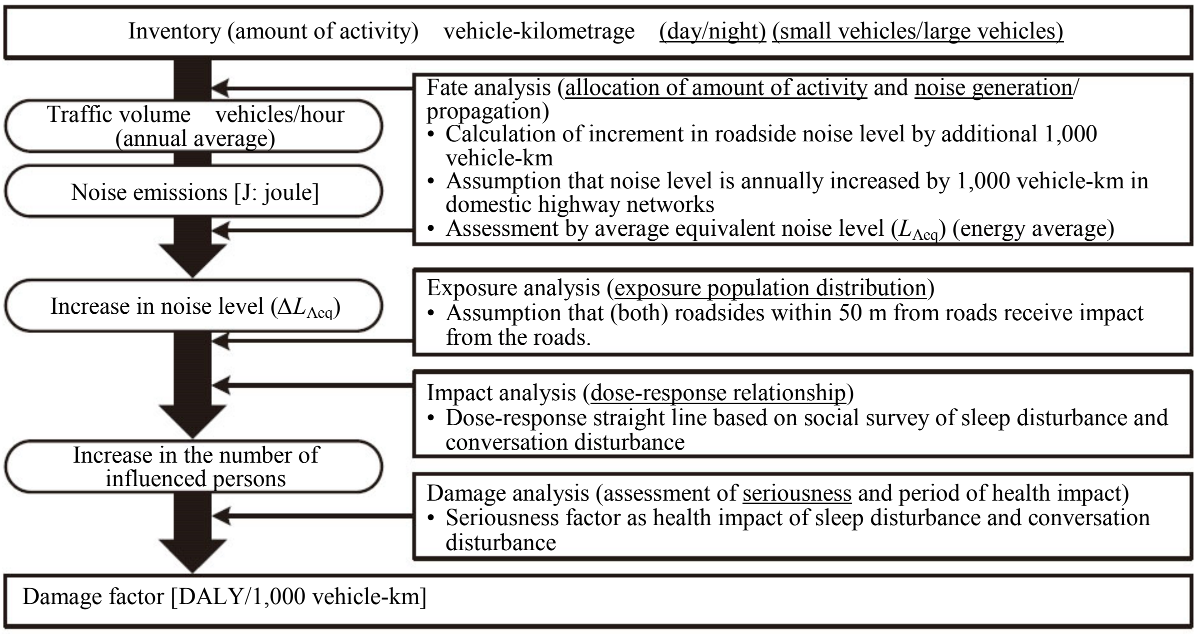

Figure 2.13-5: Flow of calculating the damage factor of noise (structure of damage function)

The underlined parts are elements about which uncertainty or variability was taken into account (see Table 2.13-5).

As in the case of Müller-Wenk, nighttime sleep disturbance and daytime conversation disturbance were selected as the objects of damage assessment (Table 2.13-4). As described above, they were taken into consideration when establishing the environmental standards for noise in Japan. Therefore, they can be thought to be representative endpoints at present.

The damage function can be calculated as follows: first, a certain vehicle-kilometrage (additional traffic volume) is allocated as an increment in the current traffic volume of the road covered by the impact assessment, to calculate the amount of increase ΔL_{Aeq} in the roadside noise level (fate analysis); next, the population (exposure population) is calculated at the noise level that can be assessed concerning the road (exposure analysis); after that, the number of cases where the exposure population receive additional impact due to ΔL_{Aeq} is calculated by the use of the dose-response relationship (impact analysis); and finally, the number is converted into DALY to calculate the damage function (damage analysis).

The underlined parts in Figure 2.13-5 are main elements about which probability distribution was considered during uncertainty analysis. An uncertainty distribution was established for all the analysis processes (Table 2.13-5).

(2) Human health: damage function for sleep disturbance and conversation disturbance

a. Fate analysis

Figure 2.13-6 shows the procedure for fate analysis of the damage function developed under LIME 2.

The basic concept of Müller-Wenk's fate analysis procedure is the allocation of marginal analysis of an additional vehicle to all road networks according to vehicle-time ratio. However, this procedure was thought to be problematic.*[13] Therefore, in this research, additional traffic volume was allocated according to vehicle-km in each road section to calculate ΔL_{Aeq}.

Nationally major roads covered by the Road Traffic Census (Column 2.13-1) were selected as roads for impact assessment. They were divided by type of road (national highway, national-government-ruled road, etc.) or by type of roadside (DID, other urban area, level area, mountainous area), and ΔL_{Aeq} was calculated for each road category if additional road volume was allocated among road categories (addition to current traffic volume). ΔL_{Aeq} was calculated for four types of inventory categories according to vehicle type (large or small vehicle) and by time zone*[14] (daytime: 6:00 to 22:00; nighttime: after that).

Table 2.13-5: Main causes of uncertainty and policies concerning the damage function of noise

Main possible causes of uncertainty	Policies for uncertainty assessment
Geographical variability (What road section had the automobile traffic volume shown in the inventory in reality?)	Establish a running density distribution according to traffic volume. Consider population density according to roadside form (assessment by road section and by roadside type) (Figure 2.13-10).
(If the distinction between daytime and nighttime is unclear in the inventory)	Establish a running probability density distribution during daytime and nighttime according to traffic volume.
(If the distinction between small and large vehicles is unclear in the inventory)	Establish a running probability density distribution of small and large vehicles according to traffic volume.
Difference in noise power level among small vehicles and among large vehicles	Establish a probability density distribution of parameters of the formula for estimation of noise power level (Figure 2.13-A).
Exposure population	Establish a uniform distribution of differences among estimation cases as possible width of roadside population estimate.
Dose-response relationship (D-R) of noise impact	Establish a normal distribution of parameters, while regarding the standard error of estimated D-R by regression analysis as standard deviation.
Degree of weight (DW) of noise impact on health	Establish a uniform distribution of DW width, which differs among studies.

[13] Calculation was made for each road section in Japan by the method used for the 1999 report according to traffic volume, traveling speed, and road width. The resultant ΔL_{Aeq} considerably differed among road networks (four-digit difference, etc.). In addition, with regard to the method used for the 2002 report, even if the total vehicle-kilometrage and the total road extension are the same, because ΔL_{Aeq} in each road section decreases as the number of road sections for calculation increases (each assessment section becomes shorter), the assessment method is physically meaningless.

[14] For the purpose of the Road Traffic Census, daytime (weekday) is from 7 a.m. to 7 p.m. (12 hours). On the other hand, for the purpose of this damage function, daytime is from 6:00 to 22:00 (16 hours) as in the case of the environmental standards. Because of this, the traffic volumes in the daytime of 12 hours and in the nighttime of 12 hours shown in the Road Traffic Census were converted into the traffic volume in the daytime of 16 hours and in the nighttime of 8 hours.

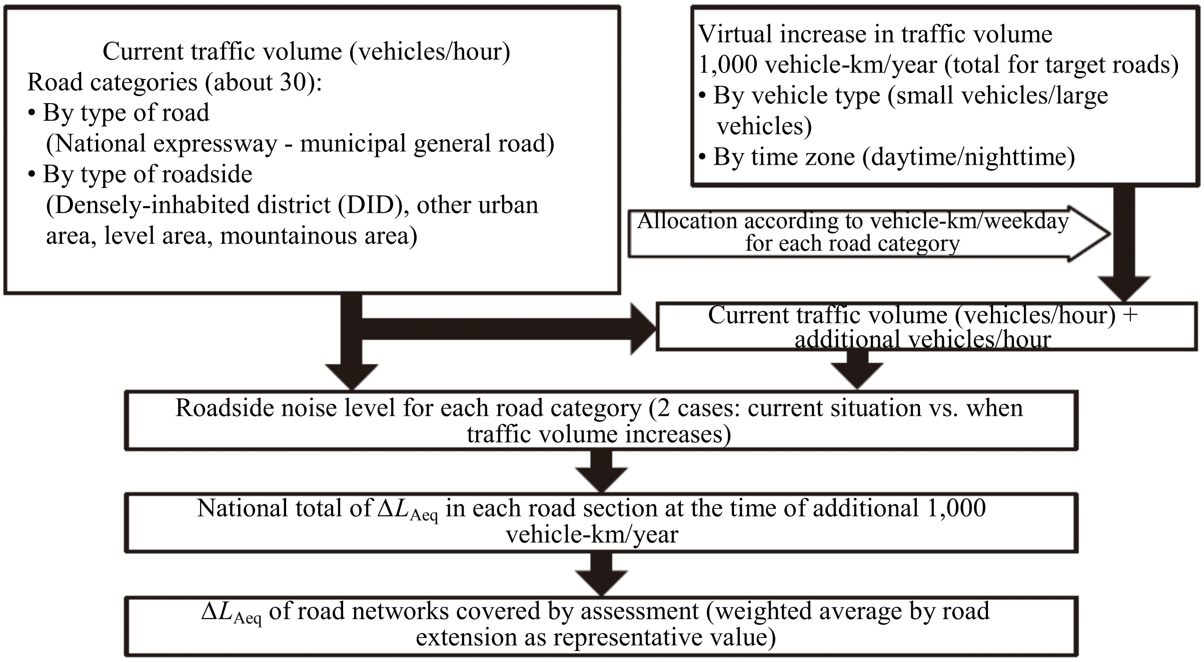

Figure 2.13-6: Fate analysis procedure under LIME 2

Column 2.13-1:

Road Traffic Census

The Road Traffic Census (the official title is the National Road and Street Traffic Census) is conducted by the Ministry of Land, Infrastructure, Transport and Tourism with the cooperation of the relevant government offices, the prefectures, the ordinance-designated cities, the expressway companies, etc. The purpose is to grasp the actual situation of the national roads and road traffic through investigation of road conditions, traffic volume, traveling speed, starting and ending points of automobiles, purposes of driving, etc. The results serve as basic data for road planning and management and for establishment of various road measures. The Road Traffic Census was conducted every three to five years from FY1928. It has been conducted every five years since FY1980. In the middle year (the third year) of the five-year period, a supplementary survey is conducted, which consists only of a general traffic volume survey.

The total weekday value for each of the above-mentioned road categories specified in the 1999 Road Traffic Census was used as current traffic value.*[15] The additional traffic volume (standard volume for damage factor) was fixed at +1000 vehicle-km/year (in Japan), as a result of trial calculation at several levels as volume within the extent that ΔL_{Aeq} increases almost linearly according to the additional volume.

Figure 2.13-7 shows an outline of the calculation of the roadside noise level, the core calculation part of the fate analysis. ASJ RTN-Model 2003 by the Acoustical Society of Japan (2004) was used for the calculation of the generation and transmission of noise. The model is widely used for environmental assessment, etc. in Japan (for details, see Column

[15] A 12-hour survey or a 24-hour survey is used as the traffic volume survey for the Road Traffic Census. With regard to the 12-hour survey section, traffic volume for 24 hours was set based on the daytime-nighttime ratio for each of the four types of vehicles in the 24-hour survey section.

2.13-2). Herein, the equivalent noise level (L_{Aeq}) (at an assumed location of roadside*[16])

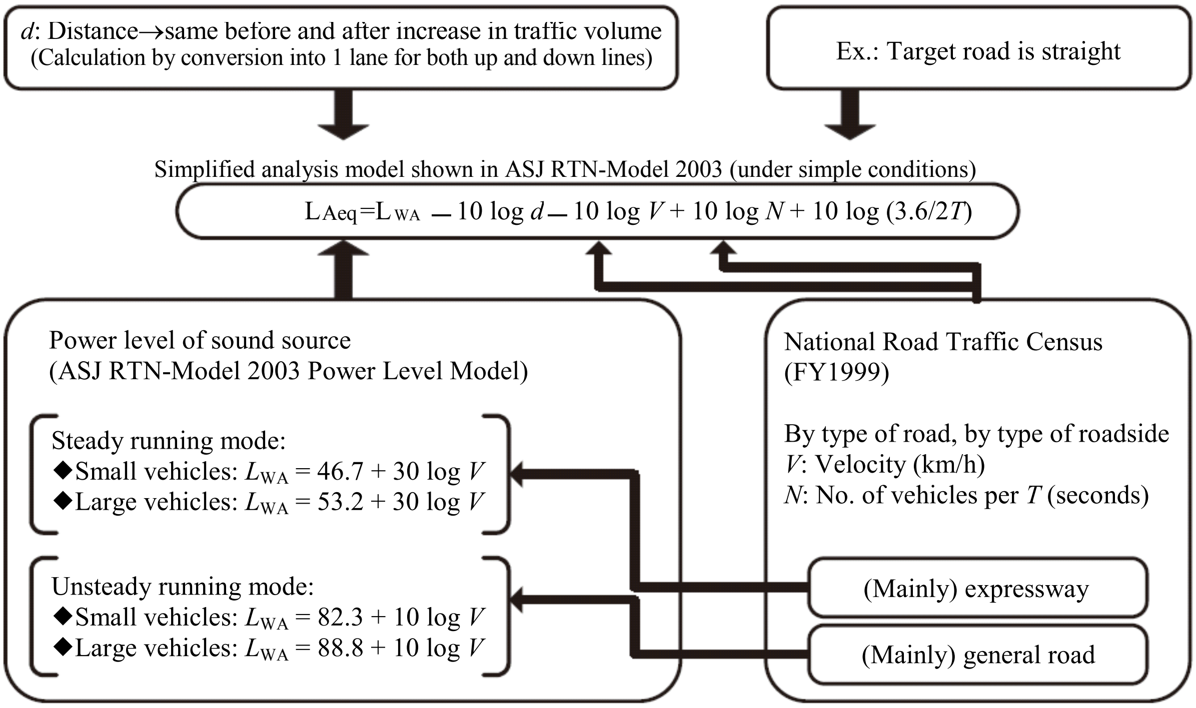

Figure 2.13-7: Calculation of noise level for each road section during fate analysis

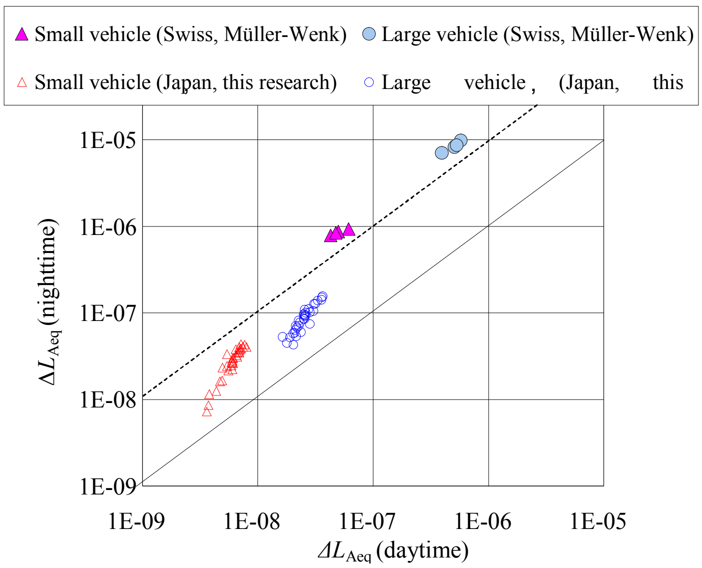

Figure 2.13-8: Distribution of ΔL_{Aeq}, increment in noise level when additional traffic volume of 1,000 vehicle-km is allocated among road sections

16 Actually, even if the traffic conditions (including traffic volume and running speed) are the same, the noise level along roadsides differs, depending on road width, planting zones, sound insulation walls, etc. In addition, the degree of decrement differs among road sections according to the existence of roadside buildings, etc. However, the object of the fate analysis for the damage function is not accurate noise level L_{Aeq} but the increment in noise level ΔL_{Aeq}, which does not depend on the roadside situation or the distance from the road within the extent that the noise from the road governs. However, depending on the content of the impact analysis described below, it may be necessary to grasp a detailed exposure situation by the exposure analysis conducted as the next analysis step.

was calculated by "the simplified calculation method of L_{Aeq} under simple conditions" concerning traffic volume (N) before and after an increase in traffic volume (current traffic volume and after allocation of additional traffic volume), and ΔL_{Aeq} was calculated marginally as the difference between the two.

Figure 2.13-8 shows the result of the calculation by the fate analysis (ΔL_{Aeq} for each road category). As shown in the figure, the result was far smaller than Müller-Wenk's result in Switzerland. Because the fate analysis procedure is not the same, they cannot be compared simply, but the reason can be explained as follows:

- The traffic volume of each road in Switzerland is smaller than that in Japan (especially during the nighttime). Because noise energy is proportionate to traffic volume, and the unit of noise level is decibel (logarithm), the noise level increases logarithmically with respect to traffic volume. Because of this, fate analysis depends on marginal analysis (increase in noise level by an additional increase in traffic volume), and therefore the noise level in Switzerland is larger than that in Japan.
- "Large vehicles" in Switzerland are larger than those in Japan (differences between the large vehicle (truck) and the small vehicle (passenger car) used at the noise power level by type of vehicle are larger in Switzerland than in Japan).

Under this calculation method, a slight difference arises in ΔL_{Aeq} among road sections because of differences in the mix rate of large vehicles. If ΔL_{Aeq} is $(\mathrm{d}L_{\mathrm{Aeq}}/\mathrm{d}N) \times \Delta N$:

$$\Delta L_{\mathrm{Aeq}} = \frac{dL_{\mathrm{Aeq}}}{dN} \times \Delta N = \frac{\Delta N}{N} \times \frac{10}{\ln 10} \times \frac{E_{vehiclecategory}}{E_{l\,arg\,evehicle} + E_{smallvehicle}} = \frac{\Delta N}{N} \times \frac{10}{\ln 10} \times E_{\%}$$

(エラー! 指定したスタイルは使われていません。-2)

In this equation, E is the noise energy of all the vehicles in a certain vehicle category, and ΔN corresponds to an increase in the number of vehicles in the category. If an additional traffic volume of 1,000 vehicle-km is allocated according to vehicle-km in each road category, $\Delta N/N$ becomes the same among the road categories, because E% differs. In an example of calculation by the use of the following representative values, the average of ΔL_{Aeq} (weighted average weighted by road extension) was calculated for both daytime and the nighttime and for both large and small vehicles and was used.

In uncertainty analysis, the parameter (difference in noise power level among vehicles) of the model used for the geographical variability and calculation of automobile traffic volume (inventory) was taken into consideration as a cause of uncertainty. The former is explained below (as for the latter, see Column 2.13-2).

As described above, ΔL_{Aeq} differs among the road categories. In the nighttime especially, a difference of about tenfold arises. In addition, although ΔL_{Aeq} is calculated for each road category in this review, if it is calculated more closely for each road section, the variability may become larger. If ΔL_{Aeq} differs among the road categories (sections), the difference in the distribution of roadside houses, etc. among them becomes a source of uncertainty at the stage of combination with impact analysis. In reality, as shown in Figure 2.13-9, ΔL_{Aeq} (inclination of curve) becomes smaller with greater traffic volume (strictly speaking, the two are not on the same curve, because of differences in the mix rate of large vehicles, speed, etc.). The figure also shows that traffic volume becomes larger with higher density of roadside population.

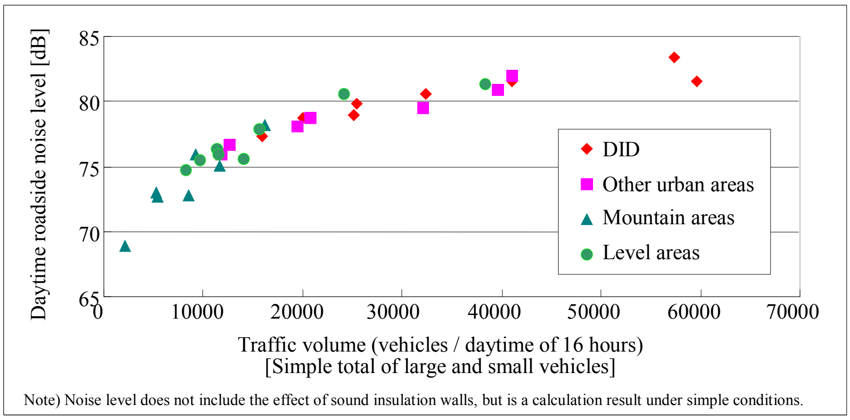

Figure 2.13-9: Relation between traffic volume and noise level in each road category (image)

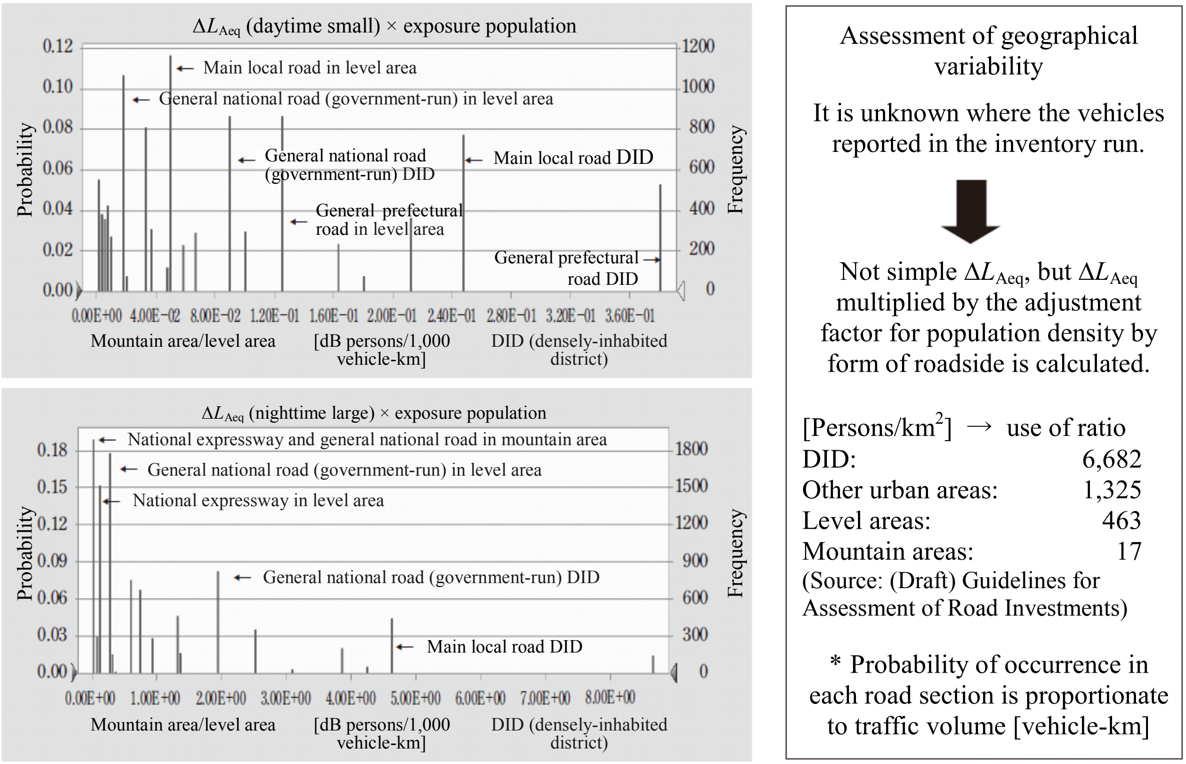

Figure 2.13-10: Setup of probability of occurrence of ΔL_{Aeq} for each road category with consideration for population density ratio

Because of this, under LIME 2, as shown in Figure 2.13-10, assessment was made of the uncertainty (variability) of the case where the vehicle-km reported in the inventory is running on any of the road categories. The probability of occurrence for each road category was assumed to be proportionate to the current traffic volume. To take into consideration differences in roadside population density, ΔL_{Aeq} was adjusted according to the ratio of population density by form of roadside.*[17] As the population density by form of roadside,

[17] On the assumption that an annual increase of 1,000 vehicle-km was shown in each road category, the increase was

the relative ratio of the values shown in the "(Draft) Guidelines for Assessment of Road Investments" (Review Committee on Guidelines for Assessment of Road Investments 1998)*[18] was used.

In other words, for the purpose of calculation by the use of representative values, the kilometrage corresponding to the inventory was "thinly and widely allocated all over Japan," while, for the purpose of uncertainty assessment, it was modeled as "running to a specific place." This can be said to be a basis for justifying the limitation of exposure assessment to the areas facing the target roads (if the noise covered by the assessment spreads all over Japan, it is possible to think that the background noise level also increases).

b. Exposure analysis

Exposure analysis can be defined as the process of finding a distribution of exposure population by noise level (and changes in the distribution). What information is needed as an output of exposure analysis can be mutually determined with the contents of the analysis processes before and after the exposure analysis.

With regard to the calculation of the number of additional impact cases (the number of impact cases added when the noise level increases by ΔL_{Aeq} due to an increase in the traffic volume) that can be found through the integration of fate analysis and exposure analysis to impact analysis, because the noise level is comparatively low when the response rate for the dose-response relationship fixed by the impact analysis described in c. below becomes 0%, no threshold level was set. In addition, the dose-response relationship was assumed to be linear. Therefore, the relationship was calculated by multiplying the population exposed to the noise in the assessed road section by ΔL_{Aeq} and the inclination of the D-R straight line.*[19]

Therefore, the exposure analysis by this damage function only requires the calculation of the population exposed to the roads covered by the impact assessment. Under LIME 2, the roadside population (13.3 million) was used as the exposure population. The roadside population was calculated by multiplying the estimated number of roadside houses shown in a reference for the Central Environment Council's report (1998) (4,673,000 houses within 50 m from the sides of the roads) (Figure 2.13-11) by the average number of household members

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divided by 365 days and by a factor representing road extension. The result was converted into an increase in traffic volume during the daytime of 16 hours and the nighttime of 8 hours to calculate ΔL_{Aeq} (in the actual calculation, it was assumed that there as an increase of 0.01 vehicle-km/year in the case of small vehicles and 0.1 vehicle-km/year in the case of large vehicles, and the result was converted into a value per 1,000 vehicle-km). To calculate population-adjusted ΔL_{Aeq} (value by which the exposure population in Japan should be multiplied), this was multiplied by the ratio of roadside population in each road category calculated from the ratio of population density by form of roadside to total population.

[18] The value is population density calculated from the populations and areas of the categories specified in the FY1997 Annual Report on City Planning (national values). Correspondence between the categories specified in the Census and those in the Annual Report on City Planning is as follows: densely-inhabited district, urban area, city planning area, and others.

[19] Because Müller-Wenk set a threshold value for the dose-response relationship, the failure to assume any threshold value for the impact analysis under LIME 2 becomes a cause for overestimation. On the other hand, Müller-Wenk included the result of estimation of noise levels for other (general) areas than areas facing (main) roads (including noise sources other than those from the roads) in the objects of assessment for exposure analysis. Because fate analysis allocates additional traffic volume only concerning highways, overestimation is highly likely to occur if the population exposed to the additional traffic volume includes the population of general areas where sound sources not from the highways may become the main cause (because noise level is logarithmic, it is inappropriate to simply add ΔL_{Aeq} to the noise level of another sound source). Under LIME 2, the extent of exposure population is both roadsides within 50 m as in the case of the assessment for the environmental standards (Ministry of the Environment "II. Regional Assessment (Areas Facing Roads)" 2000), which is conveniently simple.

(2.85) calculated based on the 1995 National Census.

Column 2.13-2:

ASJ RTN-Model 2003

1) Basic equation for calculation of the noise power level

Under ASJ RTN-Model 2003, the basic equation for a calculation model of noise power level L_{WA} [dB] is the function of velocity by type of vehicle, V [km/h].

$$L_{WA} = a + b \log_{10} V + C \quad (1)$$

The parameters of the basic equation indicate the steady state and the unsteady state concerning 4-type classification and 2-type classification.

Table 2.13-A: Value of the constant (*a*)

	Vehicle type	Unsteady running section		Steady running section	
Small vehicle	Passenger car	82.3	82.0	46.7	46.4
	Small freight car		83.2		47.6
Large vehicle	Midsize vehicle	88.8	87.1	53.2	51.5
	Large vehicle		90.0		54.4

Source: Acoustical Society of Japan (2004)

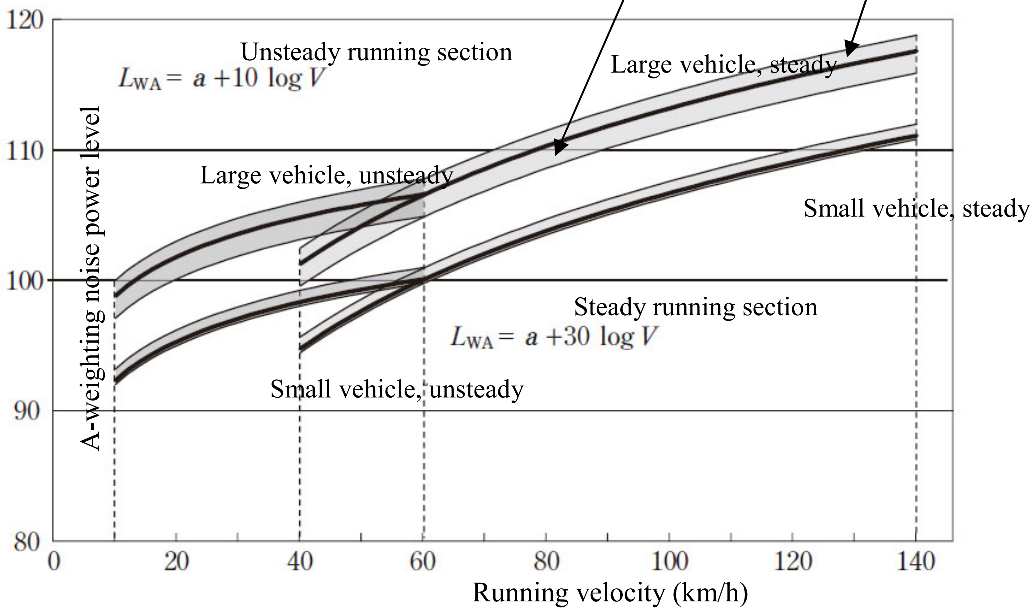


Figure 2.13-A: Difference in noise power level and establishment of an uncertainty distribution of parameters

Source: prepared based on Acoustical Society of Japan (2004)

The 2-type classification (large and small vehicles) was applied for the damage function. A model of steady state and a model of unsteady state were used for expressways and general roads, respectively. However, even in the case of expressways, if the running velocity is lower than the scope of application of stable state in a road section (by type of road and by type of roadside), unsteady state was applied. C is a correction term representing the properties of the road surface, the road inclination, etc. Under LIME 2, C was fixed at 0. The rush-hour average travelling velocity [km/h] for each of the above-mentioned roads shown in the Road Traffic Census was used as the running velocity.

In reality, noise power level differs among vehicles. Basically, it seems to become higher as the size of vehicle is larger. If the size is the same, the level may differ according to type of vehicle. To assess the uncertainty of this, the range of the parameter *a* was set up as an uncertainty distribution by the use of the parameter of the power level of the 4-type classification.

2) Analysis formula for equivalent noise level under simple conditions

To calculate the equivalent noise level $L_{\mathrm{Aeq},T}$, in principle, ASJ RTN-Model 2003 performs energy integration of temporal changes (unit pattern) in the noise of an automobile at the prediction point for the calculation of noise transmission by traffic lane and by type of vehicle. However, if it is all right to ignore sound diffraction and ground surface effects because the road is straight, $L_{\mathrm{Aeq},T}$ can be calculated analytically. Because the latter calculation method was used under LIME 2, the simplified calculation method of $L_{\mathrm{Aeq},T}$ under simple conditions shown in the Acoustical Society of Japan's reference 3 (2004) is excerpted and summarized below.

$L_{\mathrm{Aeq},T}$ can be expressed as the following equation by the use of the single noise exposure level L_{AE} (N_T is the number of automobiles passing at the target time T [s]):

$$L_{\mathrm{Aeq},T} = L_{\mathrm{AE}} + 10\log_{10}\frac{N_T}{T} \qquad (2)$$

If L_{WA} is calculated when a non-directional point sound source moves at a certain velocity on a straight and infinitely-long road and is substituted in the above equation, the relational expression between $L_{\mathrm{Aeq},T}$ and L_{WA} can be gained as shown in the equation below, which is shown also in Figure 2.13-7 (d is the distance from the position of the traffic lane):

$$L_{\mathrm{Aeq},T} = L_{\mathrm{WA}} - 10\log_{10}d - 10\log_{10}V + 10\log_{10}N_T + 10\log_{10}\frac{3.6}{2T} \qquad (3)$$

If the power level model in 1) above is substituted, the following equations can be derived concerning unsteady running and steady running, respectively:

$$L_{\mathrm{Aeq},T} = \alpha - 10\log_{10}d + 10\log_{10}N_T + 10\log_{10}\frac{3.6}{2T} \qquad (4)$$

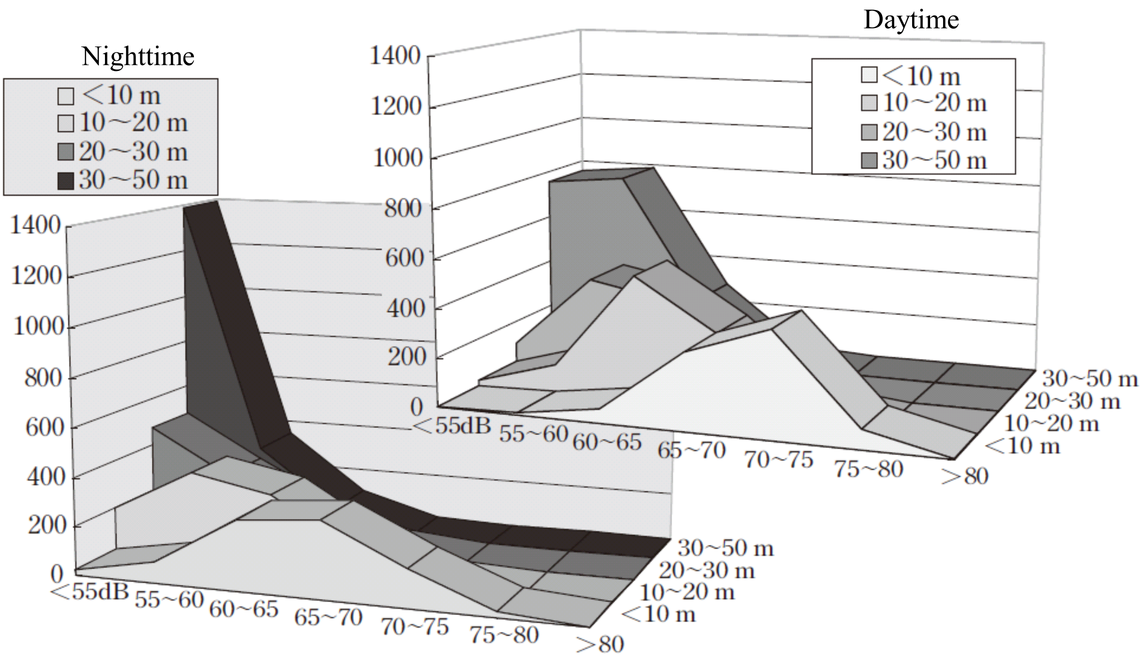
$$L_{\mathrm{Aeq},T} = \alpha - 10\log_{10}d + 20\log_{10}V + 10\log_{10}N_T + 10\log_{10}\frac{3.6}{2T} \qquad (5)$$

This process includes the following causes of uncertainty in addition to those mentioned in footnote *[7].

- The roads about which exposure population is assessed have been limited. If ΔL_{Aeq} is calculated by allocating additional traffic volume among the roads that constitute the assessed road networks, because ΔL_{Aeq} becomes larger with a smaller number of roads, limitations on the number of roads covered by the assessment do not necessarily lead to underestimation or overestimation. Differences in assessment results depend on differences between the state of distribution of houses along the roads covered by the assessment and that along the other roads.
- An estimated population along the roads covered by the assessment (Matsuhashi and Moriguchi 2000) pointed out that, although the method used in the Central Environment Council's report seems simple and appropriate for the estimation of exposure population in Japan, the actual state of population distribution in each region may not be reflected accurately. In addition, the roads covered by the estimation have been limited to the

sections that exist in the use districts.

- The distribution ratio of exposure population (number of houses, etc.) by noise level (however, this does not pertain to the review, because no threshold value has substantially been fixed and a linear dose-response relationship has been used.)
- The number of houses was converted into population by the use of the national average number of household members.



(Ministry of the Environment's noise map DB system; 1994 Road Traffic Census, within use districts)

Figure 2.13-11: Number of houses exposed to excessive noise level (number of houses by distance from roadside; unit: 1,000 houses)

Source: prepared based on a reference for the Central Environment Council's report (1998)

In the uncertainty analysis, the roadside population was estimated with a certain range. Concretely, because the roadside population differs by about 20% between that based on the above-mentioned reference to the Central Environment Council's report (result of estimation by the "Noise Map DB System") and that based on local governments' reports on spatial assessment (KCS Corp. 2003), the range was set up as a uniform distribution.

c. Impact analysis (dose-response relationship)

Under LIME 2, we referred to the "Comprehensive Research on the Assessment of Noise Impact" (Institute of Noise Control Engineering of Japan 2001, 2003), which was conducted by the Ministry of the Environment from FY2000 as a social survey on noise impact of road traffic (Column 2.13-3), rearranged the survey results by type of survey respondent, and established a dose-response relationship (occurrence ratio of sleep/conversation disturbance to the noise level outside a building) necessary for the damage function.

Under LIME 2, a survey was conducted, which included items necessary for the judgment below in addition to the noise level in houses (outdoors). The number of responses to the survey was 534. Responses were regarded as having answered "there was disturbance" if they met all the following conditions: "sleep disturbed"*[20] and "conversation (telephone)

[20] With regard to sleep disturbance, the research report (Institute of Noise Control Engineering of Japan 2001-2003)

disturbed" were given as answers to the question "nuisance from noise (multiple answers allowed)"; "very loud" was given as an answer as the degree of the noise from a road (automobiles); and "road" is given as an answer to the question "the loudest annoying noise." Results were summarized by 5-dB interval of noise level. The ratio of respondents answering "there is disturbance" was calculated for each interval. With regard to the result, linear dose-response relationships were established by regression analysis as shown in Figures 2.13-12 and 2.13-13.

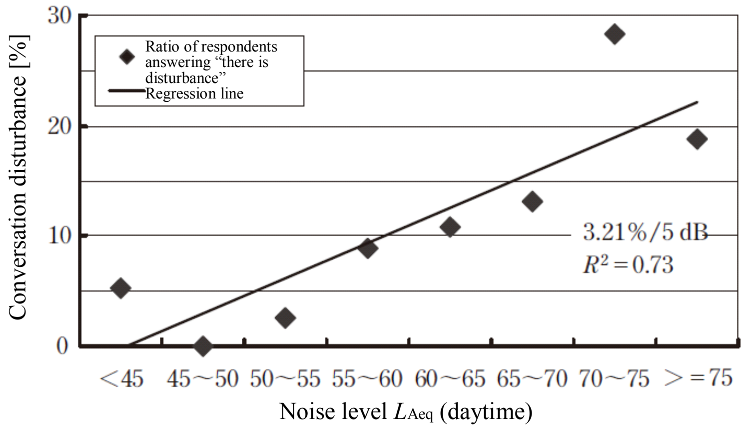


Figure 2.13-12: Dose-response relationship and basic data (daytime)

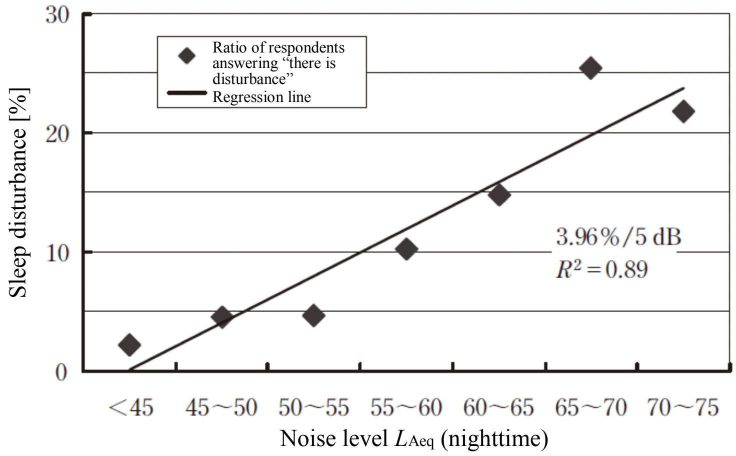


Figure 2.13-13: Dose-response relationship and basic data (nighttime)

The answer to the question about the degree of noise was limited to "very loud," because DW (degree of weight) of Müller-Wenk is used for the damage analysis described in d. below and is applied to similar annoyance. Although Müller-Wenk included the frequency of disturbance as a condition for summary, the frequency is unknown and is not taken into consideration in the data used for LIME 2.

There is a certain ratio of respondents giving an answer to the effect that there is disturbance even at a low noise level,*[21] and under LIME 2, no threshold value was substantially fixed. Because of this, the exposure population covered by the impact assessment may have been

describes as follows: "Trends in the ratio of respondents answering "receiving sleep disturbance" differ from year to year. Throughout the three years, there were differences in response among districts. There is the impact of noise from a side road in districts where the noise level of a highway is low."

21 This may be caused by something other than road traffic noise or by insufficient reflection of unexpected loud noises, because the assessment index at the noise level is a temporal average (also see footnote 8).

overestimated, while the inclination of the dose-response relationship may have been underestimated. The function form of the dose-response relationship will be discussed in 2.13.3 (3) b, together with comparison with the results of other noise impact studies.

In the uncertainty analysis, attention was paid to the inclination of the dose-response line, and an uncertainty distribution was established by a normal distribution by adopting the standard error in the parameter (inclination) estimated by the above-described regression analysis (daytime: 0.80%/5dB to an inclination of 3.21%/5dB; nighttime: 0.62%/5dB to an inclination of 3.96%/5dB).

d. Damage analysis (assessment of loss of life expectancy)

Under LIME, neither age weighting nor time discount were conducted in the assessment of the damage amount by use of DALY (Itsubo et al. 2005). Moreover, because premature death is not assessed for the damage function, the damage amount (damage factor) can be calculated by “number of impact cases × DW (degree of weight, disturbance weighting factor) × disturbance period.”

DALY-based research on burden of disease in the world (Murray 1996) does not show DW corresponding to noise impact. This is an important issue concerning the calculation of the noise damage function.

Under LIME 2, DWs of sleep disturbance and conversation disturbance were fixed based on the results of questionnaires to doctors shown in Müller-Wenk’s report in 2002 (Figure 2.13-14). Through the questionnaires, explanation was given to 64 doctors about the concrete impacts of sleep and conversation disturbance. Moreover, the existing values of DW (in addition to the list that covers the range between 0 and 1 for various types of health conditions, with regard to sleep disturbance, for example, similar cases, such as benign prostate hypertrophy (DW: (1-) 0.96), which is a nighttime symptom, and light to moderate asthma (DW: (1-) 0.97)) were shown and, after that, the doctors were directly asked about the value of DW in cases where such impacts were generated at least several times a week or every day. Valid responses were obtained from 41 doctors. Under LIME 2, F-test (5%) was carried out by the use of the average value calculated after the exclusion of outlier responses (Table 2.13-6).

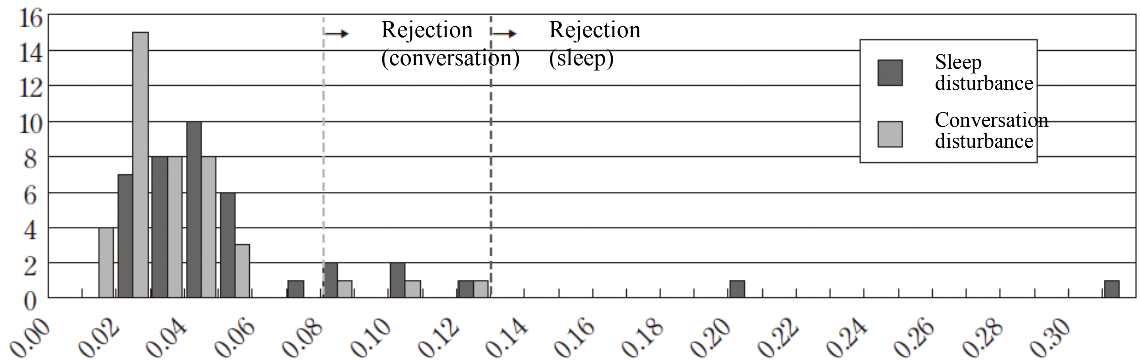


Figure 2.13-14: Questionnaire result (prepared from Müller-Wenk (2002))

Table 2.13-6: Setting up of DW of conversation and sleep disturbance due to noise

DW/case	Müller-Wenk (2002)	Müller-Wenk (2002) +F test 5% rejection	de Hollander (1999)
Conversation disturbance	0.033	0.028	0.01 (annoyance)
Sleep disturbance	0.055	0.045	0.01
Grounds for setting up	41 doctors responded numerically.		Unknown

As another research case, de Hollader et al. (1999) shows a value, although the grounds for setting up could not be confirmed. In the uncertainty analysis, a uniform distribution was established, using the value as the lower limit and the above-mentioned average value as the upper limit.

As described above, DW of noise impact depends on overseas assessment cases under LIME 2. In the field of noise impact assessment in Japan, Kabuto (2005) shows the opinion that it is possible to apply Müller-Wenk's method to Japan, but expert meetings and consensus meetings are necessary to discuss to what extent the two impacts should be regarded as burdens of disease. Recently, attention has been drawn to the assessment of health risks of cardiac and other diseases due to traffic noise as cited in 2.13.1 (2). The reflection of this may be a future problem.

Column 2.13-3:

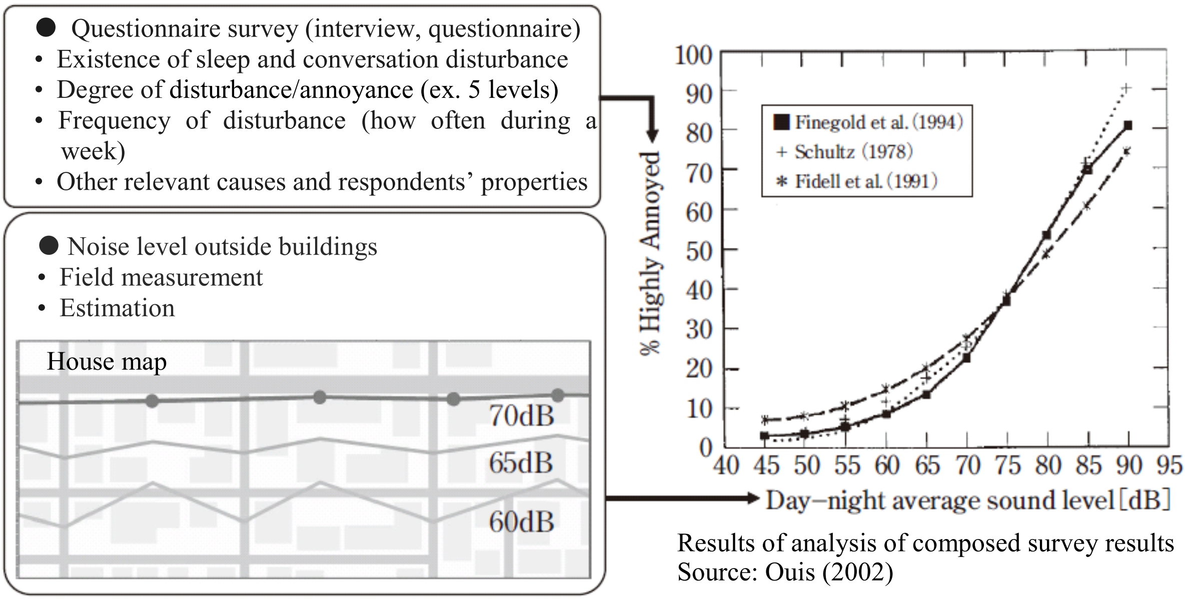
Social survey of noise impact (dose-response relationships)

A social survey is an effective method often used for the impact assessment of noise. In many social surveys, inhabitants' awareness of noise impact and relative elements are investigated and analyzed in combination with the actual measurement and estimation of noise levels outside houses.

Schuitz (1978) is famous study about the relation between traffic noise and inhabitants' awareness based on the reanalysis of results shown in 11 documents about the ratio of inhabitants answering "highly annoyed."

The environmental standards for noise in Japan have been established on the basis of the "indoor guideline values" that should be maintained to prevent impact on sleep and conversation and, at the same time, take into consideration such a dose-response relationship concerning annoyance. The Central Environment Council's report (1998) states that the results of Schultz (1978) have generally been supported through the process of accumulation of study and after that as scientific knowledge on noise impact and cites the results of studies by Finegold (1994) and others. Finegold (1994) separately examined aircraft noise, automobile noise, and railway noise and asserted that response differs according to noise source.

TNO, an independent research institute in Holland, has created an international data archive of social surveys on noise (Yano 2005). Position papers issued by the European Commission (2002, 2004) concerning the dose-response relationship about annoyance and sleep due to noise were based on the reports of surveys commissioned to TNO (2000, 2002).



Results of analysis of composed survey results
Source: Ouis (2002)

Figure 2.13-B: Image of noise society survey (left) and dose-response relationships based on studies after Schultz (1978) (right)

In the field of LCIA, Müller-Wenk (2002) calculated the dose-response relationship based on data from a noise social survey conducted on about 2,000 people in Switzerland in 1991, regarding responses of "frequently disturbed (every day or once or more every two or three days)" and "highly annoyed" as cases where "there is impact," and applying a linear equation to daytime noise level sections and nighttime-converted ones.

The "Comprehensive Research on the Assessment of Noise Impact" referred to under LIME 2 has been conducted by the Ministry of the Environment since FY2000 to enrich knowledge on impact on sleep and annoyance as a material for making appropriate scientific judgment about environmental standards. The FY2000 to FY2002 versions (commissioned to the Institute of Noise Control Engineering of Japan) include the following three types of surveys along highways; (1) survey of domestic and overseas documents; (2) social survey (questionnaire survey (visiting interview) and noise exposure survey (field measurement, etc.) (FY2000: 342 samples in Osaka Prefecture, Kanagawa Prefecture, Shizuoka Prefecture, Nagoya City, and Hyogo Prefecture; FY2001: 344 samples in Kanagawa Prefecture, Chiba City, and Osaka Prefecture; FY2002: 370 samples in Kanagawa Prefecture, Chiba City, and Nagoya City)); and (3) sleep impact survey (measurement of arousal response from body motion).

With regard to (2), research reports (Institute of Noise Control Engineering of Japan 2001, 2003) state that the degree of satisfaction about regional quietness corresponds to the daytime noise level and that there is a clear dose-response relationship between the sense of being a victim (annoyed, noisy) due to sound from a road and the daytime noise level.

e. Result of calculation of damage function

Table 2.13-7 shows the result of calculation of the damage function in addition to the result of each of the above-described processes.

Table 2.13-7: Result of calculation of the damage function (if uncertainty is not considered)

	Daytime (6:00 to 22:00) [Conversation disturbance]		Nighttime (22:00 to 6:00) [Sleep disturbance]	
Vehicle type	Small vehicle	Large vehicle	Small vehicle	Large vehicle
(1) ΔL_{Aeq} (μ dB/1,000 vehicle-km)	0.0065	0.023	0.032	0.078
(2) Population exposed to noise from road	13.3 million			
(3) Inclination of D-R (Increase in the number of impact cases as a result of an increase in the noise level)	0.64%dB		0.79%dB	
(4=1×2×3) Number of additional impact cases as a result of increase of 1,000 vehicle-km	0.00055	0.0020	0.0034	0.0082
(5) Weighting of disorder (DW) during a year	0.028		0.045	
(6=4×5) damage factor (DALY/1,000 vehicle-km)	1.6E-5	5.6E-5	1.5E-4	3.7E-4

Because this table indicates the process of calculation, the values differ from representative values for uncertainty assessment.

(3) Damage factor of noise

a. Result of uncertainty analysis of damage factor

As described above, Monte Carlo analysis was conducted with consideration for the following: geographical viability as to in what road category the automobile traffic volume shown in the inventory ran; the width of the estimated roadside population; the standard error in D-R estimated by regression analysis; and DW, which differs among studies. Details of the establishment of these distributions are as described concerning each of the elements of the above-mentioned damage factor.

Figure 2.13-15 shows a probability density distribution of the damage factor in cases where the distinction between the daytime and the nighttime or between small and large vehicles is unknown (these probabilities are set from the current traffic volume). If the causes that most influence the viability of the result are examined based on the rank correlation coefficient (Table 2.13-8), the highest influential cause is differences in the traffic and roadside situations according to road category, the second highest is the difference between the daytime and the nighttime, and the third highest is the difference between small and large vehicles.

Given that it seems difficult to add, to the inventory, geographical information that distinguishes where vehicles run, it is possible to reconfirm that the division of the damage factor between the nighttime and the daytime and between small and large vehicles is reasonable for (efficient) improvement of the reliability of noise impact assessment by LCA.

Table 2-13-9 shows the statistical value of the damage factor classified between the nighttime and the daytime and between small and large vehicles. The table shows that the variation factor for large vehicles is larger than that for small vehicles. The table also shows that if vehicle type and time zone can be distinguished, the variation factor is reduced from 3.2 to around 1.5 or 2. The main cause of uncertainty by vehicle type and time zone is road sections where vehicles run (geographical variability).

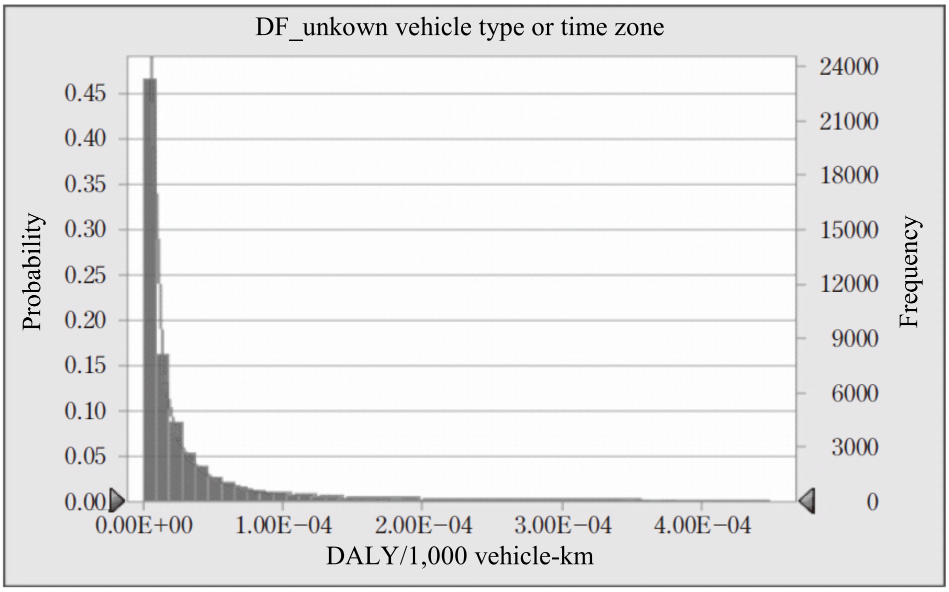


Figure 2.13-15: Result of uncertainty analysis (if vehicle type or time zone is unknown)

Table 2.13-8: Noise damage factor (rank correlation in case of unknown vehicle type or time zone)

Variable	Rank correlation coefficient
Road category (daytime, small)	0.54
Selection of vehicle type and time zone	0.45
DW (conversation disturbance)	0.15
Road category (daytime, large)	0.14
D-R (conversation disturbance)	0.12
Road category (nighttime, small)	0.09
Noise PWL small vehicle (passenger/small freight)	0.05
DW (sleep disturbance)	0.04
Road category (nighttime, large)	0.04
Estimated roadside population	0.03
Noise PWL large vehicle (midsize, large)	0.03
D-R (sleep disturbance)	0.02
Selection between daytime and nighttime (small vehicle)	0.01

- Limited to cases where the rank correlation coefficient is 0.01 or more.
- Fluctuation is high among road categories (roadside situations).
- The table shows that the distinctions between the daytime and the nighttime and between small and large vehicles (selection of vehicle type and time zone) are also important.
- Large daytime traffic volume is reflected in the table.

Table 2.13-9: Statistical value of damage factor (examples)

Running category	Small vehicle Daytime	Large vehicle Daytime	Small vehicle Nighttime	Large vehicle Nighttime	Unknown vehicle type/time zone
No. of trials	50,000	50,000	50,000	50,000	50,000
Average	1.35E-05	4.53E-05	1.28E-04	2.78E-04	4.64E-05
Median	7.14E-06	1.89E-05	7.01E-05	7.88E-05	1.07E-05
Standard deviation	1.73E-05	7.11E-05	1.61E-04	5.25E-04	1.46E-04
Dispersion	2.98E-10	5.06E-09	2.59E-08	2.76E-07	2.13E-08
Variation factor	1.28	1.57	1.26	1.89	3.15
10% value	5.61E-07	6.78E-07	5.88E-06	1.75E-06	7.26E-07
90% value	3.60E-05	1.22E-04	3.26E-04	7.75E-04	9.79E-05
Average standard error	7.72E-08	3.18E-07	7.19E-07	2.35E-06	6.53E-07

b. Comparison with existing studies on the damage factor

The calculation result of the damage factor (representative value) is smaller than those shown in Müller-Wenk (2002) (especially, those for the nighttime and large vehicles). This is because of the following reasons: (1) difference in the above-mentioned fate analysis (because of marginal assessment, ΔL_{Aeq} is smaller in Japan, where traffic volume is relatively large (especially during nighttime); moreover, the power level of large vehicles compared with small vehicles is larger in the case of the Swiss model); and (2) difference in the linear dose-response relationship (D-R) (the inclination is more gradual in this review).

With regard to (2), TNO (2002) compared the result concerning sleep disturbance under LIME 2 with the D-R for sleep disturbance created based on the archive on the results of studies conducted in several countries.

Figure 2.13-16 shows that the inclination set up by Müller-Wenk (2002) is far steeper than that for “A little sleep disturbed” by TNO and that the inclination in this review is closely similar to that for “Highly sleep disturbed” (consistent with the definition used for the application of DW to the result of D-R in Müller-Wenk (2002)) (however, it is smaller in the case of 60 dB or more*[22]). Therefore, it can be thought that the inclination of the D-R set up under LIME 2 is not so greatly underestimated.

c. Verification by comparison with “spatial assessment” (spatially explicit assessment)

In the fate analysis, the damage function developed under LIME 2 was calculated by using the result of summation of information on road categories with different traffic conditions in Japan according to type of road and form of roadside and applying the formula for calculating the noise level under simple conditions, regarding the road as a line at infinity. Moreover, ΔL_{Aeq}, the resultant increment in the noise level, was assumed to be the national uniform average, and impact analysis was conducted with regard to the result of multiplication of the increment by the exposure population in Japan. Although the uncertainty analysis took into consideration differences in ΔL_{Aeq} among the road categories, consideration of roadside

[22] If a quadratic function is applied to the data used for this review by the least-squares method, parameters are estimated as convexes not downward but upward. Because of this, it was decided that the dose-response relationship should remain linear.

population density has been limited to the differentiation of four types. As described above, the damage function is a very rough estimate of the state of exposure to noise.

In Japan, new environmental standards for noise were promulgated in 1998 to change the index of noise level to equivalent noise level (L_{Aeq}), and shifted the local governments' assessment of the environmental standards for noise from so-called "point assessment" to "spatial assessment." During the spatial assessment, the results of investigation of the location and form of a building are usually included in the Geographic Information System (GIS) and are combined with the results of prediction of noise levels (from the noise level on the side of a road (actually measured value) to the attenuated noise level in the building).*[23]

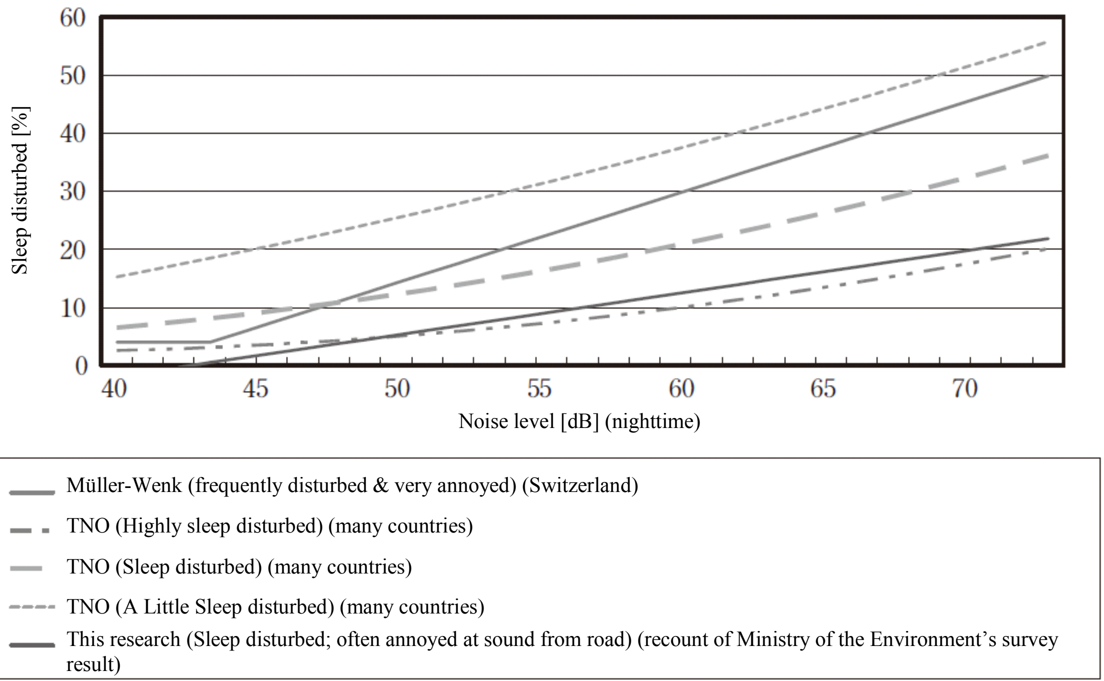


Figure 2.13-16: Comparison of dose-response relationships in sleep disturbance

When LIME was developed, cooperation was obtained from the local governments that widely carried out spatial assessment.*[24] This made it possible to conduct fate analysis and exposure analysis minutely in the districts covered by the spatial assessment and compare the results with those of the assessment based on rough count like the damage function for LIME.

Although the results are not described in detail herein due to space limitations, if the traffic volume of large vehicles increases in the target area, the number of cases where additional impact occurs (damage factor) is smaller in the case of spatial assessment. On the other hand, the contrary result was gained in the case of small vehicles. When the cause was examined, the following two facts were found:

1) Gap due to fate analysis: It was found that the integration of road sections influences the

[23] For example, see the special feature in "Noise Control," 29 (2), the April 2005 issue.

[24] The borrowed data do not include noise measurement results (actual measurement values). The results of the review described below are mere results of estimation by model calculation based on traffic volume. Because of this, the results of the estimation are inconsistent with the results of assessment of the local governments' environmental standards.

result. That is, the mix rate of large vehicles through recalculation of traffic volume on a vehicle-km basis for the preservation of traffic volume before and after the integration, q, is not the same as the q calculated by weighted average on a distance basis. However, from the viewpoint of fate analysis, which requires overlapping with the distribution of roadside residences, the environmental impact result does not change before and after the integration in the case where q is calculated by weighted average on a distance basis. To what extent such a gap occurs depends on the strength of the correlation between the traffic volume in each road section in the area covered by the assessment and the mix rate of large vehicles.

The Road Traffic Census was used to analyze the relation between the traffic volume in each road section and the mix rate of large vehicles in the districts covered by the spatial assessment and in Japan. According to the result, in the districts covered by the spatial assessment, the mix rate of large vehicles tends to be higher with higher traffic volume in the case of a long general road. In Japan, it does not necessary tend to be higher in the case of a long general national or regional road. This seems to stem from distortion due to the totaling being smaller than in the districts covered by the spatial assessment.

2) Gap due to exposure analysis: To examine the cause of a gap due to exposure analysis, clarification was made about the relation of the extension of a road section and the number of roadside houses with the mix rate of large vehicles in the districts covered by the spatial assessment. According to the result, in the districts covered by the assessment, the mix rate of large vehicles is smaller from the viewpoint of the number of exposed houses. The reason for this seems to be that not the roadside average but the housing average is at least a cause for a small increment in the noise level ΔL_{Aeq}. However, this has not been verified at the national level.

2.13.4 Procedure for the impact assessment of noise

(1) Method for the assessment of impact on products, and points that require attention

a. Procedure for LCIA of general products, and points that require attention

If various environmental impacts were integrally assessed concerning general products, etc., it is expected that the application of the damage factor of noise shown in 2.13.3 and the integration factor based on them will improve the underestimation of the environmental impacts during the stage of transportation in particular. However, because the damage function is used only for the assessment of automobile traffic, attention is necessary if modal shift or the like is included in the comparison among the objects of assessment.

It cannot be expected that ordinary inventory analysis will include generated noise energy as a data category. Therefore, LIME 2 shows the impact assessment factor per vehicle-km by type of automobile and by time zone for running. Because running distance is not environmental emission, it can be thought that it is often not included in the final result of the inventory analysis. However, with regard to the existing LCA software, for example, the transportation means should be selected and the loading ratio and the transportation distance should be inputted. If estimation is made about such existing information, it is possible to grasp vehicle-km by transportation means.*[25]

[25] However, if vehicle-km is presented in the result of the inventory analysis together with emissions of greenhouse gas and emissions of air pollutants, it may become difficult to know whether emissions of greenhouse gas, etc. due to automobile

The calculation procedure for impact assessment is as shown in the equation below. In this equation, *vehicle_type* is type of vehicle (running category) and *time* is time zone for running (daytime (6:00 to 22:00), nighttime (22:00 to 6:00), or unknown). *Inv* is vehicle-km by type of vehicle and by time zone. However, the characterization factor is the same irrespective of time zone. With regard of type of vehicle, the 2-type classification (small and large vehicles) or the 4-type classification (or unknown) is applied to the characterization factor, while the 2-type classification (or unknown) is applied to the damage factor and the integration factor. Details of the definition of each type are referred in the notes to Table 2.13-3. In the case of ordinary freight transportation, if the 2-type classification is adopted, the damage factor for large vehicles is basically applied, excluding the application of the damage factor for small vehicles to small freight vehicles. From the viewpoint of damage assessment, it is more important to grasp difference in time zone for running than to grasp vehicle types as shown in (3).

Characterization:

$$CI^{Noise} = \sum_{vehicle\_type} CF^{Noise}(vehicle\_type) \times Inv(vehicle\_type)$$ (エラー！指定したスタイルは使われていません。-3)

Damage assessment:

$$DI^{DALY} = \sum_{vehicle\_type,time} DF^{Noise}(vehicle\_type,time) \times Inv(vehicle\_type,time)$$ (エラー！指定したスタイルは使われていません。-4)

Integration:

$$IF = \sum_{vehicle\_type,time} IF^{Noise}(vehicle\_type,time) \times Inv(vehicle\_type,time)$$ (エラー！指定したスタイルは使われていません。-5)

b. Adaptability to parts of automobiles, automobile parts, etc. (assessment of difference in quietness)

For the purpose of the damage function, vehicle-km is assumed to be the unit of the inventory, and differences in the properties of vehicles have been defined according to rough classification, such as large and small vehicles. Because of this, the procedure described in a. above can be used for including noise in the LCA of automobiles, also taking into consideration other impact categories, but cannot be applied to the assessment of difference in quietness.

Logically, if the noise power level (expression of relation with velocity during steady and unsteady running) of the specific vehicle type to be assessed can be used and some damage functions can be rearranged, the damage factor of the vehicle type can be calculated.

If the noise power level increases by 10 dB (*n* dB), for example, the increment in the noise

running are included in the above-mentioned value. Therefore, it seems desirable to specify the way of dealing with this point.

level (therefore, the damage factor also) increases tenfold ($10^{n/10}$ times). If this relation is used, it seems possible to reflect the improvement of quietness in the assessment in the form of by how many dB the noise power level is reduced from before.

To improve the applicability to such purposes of use, it is necessary to express a damage function as the product of the part used for the calculation of the noise energy amount generated from vehicle-km and the part used for the calculation of the damage amount from the noise energy amount (Ii et al. 2009). The characterization factor under LIME 2 falls under the former. Because this arrangement can make it possible to express the inventory by the unit of not vehicle-km but noise energy amount, it is advantageous from the viewpoint of conformity with the definition of the basic flows – that is, the input and output flows of substances and energy.

(2) Relation with other impact assessment

Because the damage function has been developed to be applied to the LCIA of products, even if road traffic noise is assessed, it cannot be used for the LCIA of buildings (that receive noise) and roads. However, it may be possible to use some elements of the damage function.

a. Buildings (assessment from the viewpoint of noise receivers)

The assessment of buildings from the viewpoint of the noise receiving side may include not only differences in location conditions but also sound insulation and other conditions related to noise. However, the damage function has been formulated from the viewpoint of the noise-generating side and therefore cannot be applied as is. Meijer et al. (2006) is a case study that incorporated noise damage in the LCIA of buildings.

b. Roads

Because the damage factor under LIME 2 indicates the national average damage, it is inappropriate to apply it to the LCIA of the construction of a specific road. Therefore, it seems necessary to conduct fate and exposure analysis in the road network to be assessed.

When government-subsidized public works are carried out in Japan, cost-benefit analysis is required. As described in the "(Draft) Guidelines for Assessment of Road Investments Volume 1" (Review Committee on Guidelines for Assessment of Road Investment 1998), a proposal has already been made about the method for assessment of noise impact for the purpose of the cost-benefit analysis of road construction. The noise impact assessment described in the (Draft) Guidelines is qualitatively based on the economic assessment method (hedonic method) concerning impact assessment and damage assessment. On the other hand, although fate and exposure analysis is conducted based on changes in the traffic situation of the road network before and after road construction, the basic concept seems similar to that of the damage function.

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