5 Land Use Damage Assessment and its Application on Resource Extraction and Waste Landfill Impact Categories in LIME2

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ABSTRACT

Land use is one of the impact categories covered in LIME (Life-cycle Impact assessment Method based on Endpoint modeling) version 1 from the beginning of its completion in FY 2002. The damage assessment method on ecosystem was developed not only for land use but also for its related impact categories in a typical product life-cycle, namely, resource extraction and waste landfill. The damage indicators are the increase of extinction risk of plant species and the loss of net primary production and they correspond to the damage categories of biotic natural environment and biotic natural resources in the LIME framework, respectively. In the development of the second version of LIME (LIME 2) since 2003, we executed quantitative uncertainty assessments on the damage functions of these categories by Monte Carlo approach. The result was compiled to the list of updated damage factors with their statistics values and information of the probability distribution functions. Furthermore, it helped to examine the future direction of the improvement of our damage analysis as well as their characteristics and limitations. In this presentation, the achievements and problems about the land use damage assessment and its application on resource extraction and waste landfill impact categories in LIME2 will be introduced and compared with some of the other methods in Europe.

LAND USE IMPACT IN LIME FRAMEWORK

LIME (Life-cycle Impact assessment Method based on Endpoint modeling) is an LCIA method developed for Japan, and the project to develop its second version, LIME2, had been launched in 2002. The major progresses since LIME1 are as follows [1]:

- Introduction of 2 new impact categories (transport noise and indoor air pollution)
- Application of uncertainty analysis on the damage factors, weighting factors and integrating factors by the Monte Carlo approach
- Improvement of representativeness and credibility of weighting factors for integration (based on a panel survey on a some thousand people)

Fig 1 shows the basic framework of LIME2. The safeguard subjects for ecosystem are biodiversity and primary production. The damage indicator of biodiversity is the increase of extinction risk of plant species and that of primary production is the amount of lost NPP (net primary production).

Land use is one of the important impact categories for ecosystem safeguard subjects in LIME. In addition, the damage factors are provided for resource extraction and waste landfill by applying the damage assessment of land use.

LAND USE DAMAGE ASSESSMENT IN LIME

In LIME, the damage function of land use has been developed for NPP and biodiversity[2, 3].

Damage Assessment for NPP (Primary Production)

The aspect of land use in the damage function for NPP is classified into the continuation of land use (land occupation) and land transformation (land change).

The damage of land occupation is calculated assuming that potential NPP is not fully achieved while the land is occupied. The damage due to land transformation is calculated by the loss of NPP during the period required for recovery of vegetation from altered to its potential state.

[Damage factor of land occupation] (Fig. 2-1)

\[ DF_{occ}^{NPP}(a) = NPP_p - NPP_a \] (kg/m²/year) (1)

[Damage factor of land transformation] (Fig. 2-2)

\[ DF_{trans}^{NPP}(b,a) = \alpha_{a \rightarrow p} DF_{occ}^{NPP}(a) \times (T_{a \rightarrow p}) - \alpha_{b \rightarrow p} DF_{occ}^{NPP}(b) \times (T_{b \rightarrow p}) \] (kg/m²) (2)

\(b,a\): Category of vegetation or landuse (before, after)
\(T\): Time required for recovery of land productivity
\(\alpha\): 0.5 (Recovery of NPP is assumed to progress linearly.)
The damage factors are prepared for each of 30 types of vegetation and 9 of land-use categories.

Damage Assessment for Biodiversity

In the damage function of land use for biodiversity, the damage indicator is the sum of increases in inverse number of expected time to extinct (T) of endangered vascular plant species due to land transformation for a unit of land. The indicator is called 'EINES' (Expected Increase in Number of Extinct Species) and calculated as follows:

\[
EINES = \sum A(1/T) = \sum (1/T_{b,i} - 1/T_{a,i})
\]  \hspace{1cm} (3)

The calculation is based on the assessment method developed by Matsuda et al.[4] following the steps shown in Fig. 3 below. The major data sources are the Red Data Book (RDB)[5] and Environmental Impact Statements (EIS's) prepared for the projects involving large-scale land alteration. The damage factors are prepared for roads, landfills, gravel pits and railways.

Resource Extraction and Waste Landfill

At the time LIME project had started, land use activities related to resource extraction and waste landfill...
had been rarely included in the inventory of LCA studies. Therefore, the damage factors for these activities were established by identifying the area and utilization time of land required for these activities and relating them to the damage factors for landuse.

For the activities that take place in Japan, the landuse inventory was prepared by referring to the EIS’s, the data of existing landfill facilities and other sources, and directly connected with the damage factors for landuse. For resource extraction in other countries, on the other hand, the area of landuse was estimated by a symple equation (eq.4) shown in Fig.4. The damage factors on NPP were obtained by estimating the global NPP, and those on biodiversity were set by correcting the Japanese damage factors. The calculation flow is shown in Fig. 4.

LIME2: REVISEMENT THROUGH UNCERTAINTY ANALYSIS

In the development of LIME2, uncertainty analyses were conducted, as well as addition and update of foundamental data for parameter setting, to revise the damage factors[7,8]. The resulting statistics and fitted probability density distribution are provided as the list of damage factors. The evauated major parameters are shown in Table 1.

The results show that the uncertainty is higher in the damage factors on biodiversity than on NPP, probably due to grater geographic variability; as EINES reflects the differences in extinction risks among species, they are influenced by the variations in plant species that grow in the area to be transformed.

Another uncertainty is the correction of damage factors on resource extraction to apply Japanese landuse factors to other countries. Also, extraction of low-grade metal involve the variation in the estimated area to be converted, acting as an important factor of uncertainty.

For landfill, the differences in the area used for each landfill are identified as a major uncertainty factor.

DISCUSSION

Comparison of Damage Indicators with Other LCIA Methods

The damage assessments on biotic production or life support functions are targeting NPP or soil quality. Lindeijer [9], a pioneer project in Europe, had developed an assessment method for fNPP (free NPP), but assessed the land occupation and land change separately. LIME, on the other hand, presented a methodology in which land occupation and land change are integrated [2]. Although Eco-indicator99 [10] attempts to integrate them, too, by applying the concept of restoration time, it does not take $\alpha$ in Equation (2) into account. Our formulation—including of $\alpha$ and assuming it to be $1/2$— is rather similar to Köllner et al. [11].
In Europe, damage assessment on biodiversity is often based upon SAR (Species-Area relationship) in community ecology (Goedkoop et al. [10], Lindeijer [9], Köllner[12], Köllner et al.[13], Schmidt [14]). PDF (Potentially Disappeared Fraction) is one of the typical damage indicators derived from SAR. PDF, however, depends on the different concept from PAF which is the major indicator in the damage assessment of ecotoxic chemicals. Moreover, it is pointed that they do not reflect the relative scarcity of species [15].

The damage assessment of land use in LIME is based on the risk assessment method (extinction probability) in conservation ecology. As stated above, ‘EINES’ considers the differences in average lifetime probability) in conservation ecology. As stated above, ‘EINES’ considers the differences in average lifetime among species. It is also applied in the ecotoxicological study and in the EINES/m2 among the evaluated EISs.

The area of land converted for extraction of a unit of some metals are compared with that in ecoinvent2 (2006) (Table 2). The results show that the amount is larger in LIME2 than in ecoinvent2. The reasons may include that the landfill areas of talings in LIME2 are not included in the ecoinvent in the table (Cu); LIME2 does not distinguish underground mines and open mines (Pb); and the differences due to overburden (Fe). Further study is needed.

Table 2 Comparison of land transformation

<table>
<thead>
<tr>
<th>Impact Category</th>
<th>Module</th>
<th>Evaluated Parameters (Probability density distributions were set for these.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Use</td>
<td>NPP</td>
<td>Parameters of Chikugo model for potential NPP, current NPP for each vegetation type and geographical distributions of 2 types of NPP, recovery time</td>
</tr>
<tr>
<td></td>
<td>EINES</td>
<td>Parameters of regression models for estimating expected time to extinction of the plant species. Estimated population of the species in Japan and in the surveyed area in the EISs, variation of the EINES/m2 among the evaluated EISs</td>
</tr>
<tr>
<td>Resource extraction (e.g. metals)</td>
<td>Land use</td>
<td>Parameters of estimating the size of land changed for the extraction (e.g. ore grade, hidden flows, thickness of deposits) for each metal, mining duration</td>
</tr>
<tr>
<td></td>
<td>NPP</td>
<td>World NPP distribution and unknown location of extraction, recovery time</td>
</tr>
<tr>
<td></td>
<td>EINES</td>
<td>Density of # of endangered species in each country, parameters of regression model for EINES conversion from Japan to the other countries, probability density function of the EINES factor</td>
</tr>
<tr>
<td>Waste landfill</td>
<td>Land use</td>
<td>Density for each waste type, variation among landfills, parameters for estimating landfill volume and area conversion ratio, duration until abandonment</td>
</tr>
<tr>
<td></td>
<td>NPP&amp;EINES</td>
<td>(see ‘Land use’ impact category)</td>
</tr>
</tbody>
</table>

**Table 1 Major parameters in uncertainty analysis**

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**REFERENCES**


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