Annual Nationwide Environmental Impact Assessment of Japanese Municipalities by Type of Business within the Endpoint-type LCIA Method “LIME2”

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Abstract. This study attempts a comprehensive environmental impact assessment, within the context of annual operations by type of business in each division of Japanese municipality, based on the LCIA (Life Cycle Impact Assessment) method. LIME2 (Life-Cycle Impact Assessment Method Based on Endpoint Modeling 2) is an example of an endpoint-type LCIA method developed in Japan. Annual environmental impacts of municipalities nationwide are assessed by LIME2 from the perspective of environmental damage, indexed to the Japanese yen. Here, this index is referred to as the “Eco-index Yen”. The availability of necessary inventory data in each category is surveyed from statistical information published by governments. From the assessment results based on these conditions, the annual damage amount of all Japanese municipalities taken together is 4.63 trillion yen. The assessment result of each municipality is converted into indicators per capita and per GRP (Gross Regional Product). These results are displayed on a map of Japan to visualize regional characteristics nationwide by type of business, across different types of industries, including the residential and transportation sectors. As described in this study, these results provide a first step toward constructing a new methodology for comprehensive environmental impact assessment of administrative units.

1. Introduction

It has become important for enterprises to create environmental policies after carefully examining their future plans and considering their relationships with the environment and the economy. The trend of enterprises self-reporting their environmental activities both quantitatively and monetarily emerged in the early 1990s, and many private companies in Japan have been early adopters. Some public agencies, such as local governments, have also actively introduced this approach into their financial accounting practices in recent years. For example, the cities of Yokosuka and Sabae publish environmental accounting on an annual basis using one-of-a-kind methods [1-2]. However, compared with private companies, it may be more difficult for local governments to measure the environmental loads of their own administrative divisions in an objective way, because of the wide scope required for a complete assessment. Moreover, no environmental accounting guidelines for public agencies have
been officially provided in Japan. Therefore, local governments must devise their own individual methods for evaluating the costs of environmental impacts. Under such circumstances, it is hard to say that environmental accounting is widely used by public agencies in Japan, especially when compared with private companies.

In the research field of life-cycle assessment (LCA), there is an idea of life-cycle impact assessment (LCIA), which is a concept whereby environmental loads throughout the life cycle of products and services are measured in a quantitative way. Included in the LCIA process is “integration,” which is the methodology whereby a number of environmental loads that affect various impact categories, such as global warming, air pollution, and land use, are integrated into an assessment result represented by a simple indicator. Assessment methods that include the theory of integration, such as ExternE [3] and EPS [4], have already been developed. However, there have so far been no cases in which this theory was officially incorporated into the environmental accounting of local governments in Japan in order to calculate the environmental loads within their administrative divisions. Previous studies that measured the environmental loads of spatial scopes, such as countries and regions, have reported results using several values, including carbon footprint and land footprint [5-9]. However, a methodology incorporating these approaches for environmental accounting in Japan has not been established, nor are there any international standards. It is therefore possible that the LCIA may prove beneficial in helping to construct a unified methodology for environmental accounting of local governments, which they can use to make informed decisions concerning local environmental policies.

In a previous study, we focused on the lowest level of administrative divisions (municipalities) in Japan and, using the LCIA method, attempted to comprehensively measure environmental loads emitted in each division during a certain period [10]. The present study is a follow-up to that previous study, and here we measure environmental loads nationwide according to type of business, including industries in the residential and transportation sectors. This study leverages the assessment theory Life-Cycle Impact Assessment Method Based on Endpoint Modeling 2 (LIME2) [11], which was developed in 2010. This is an endpoint-type LCIA method and can be used to calculate environmental impacts that reflect environmental conditions and knowledge unique to Japan. LIME2 incorporates the “integration” theory of LCIA and calculates assessment results in monetary units called the “Eco-index Yen” (unit: Japanese yen) while integrating the environmental loads of several impact categories. The aim of this study was to capture the circumstances of local governments with respect to environmental accounting as comprehensively as possible within the range of LIME2, using statistical information by type of business available in Japan. The assessment results of environmental loads were divided by the population and annual gross regional product (GRP; unit: Japanese yen) of each municipality to quantify environmental efficiency during a given period according to certain criteria. The results were placed on a map of Japan to visualize the regionality of these concepts. Through comparative examination of the environmental loads of Japanese municipalities based on these indicators, this study sought to provide new insights to aid public administrators in their decision-making process with respect to environmental policies.

2. Assessment Method

2.1. Basic Assessment Points

This section describes basic points for assessing comprehensive environmental loads and the environmental efficiency of administrative divisions of Japanese municipalities. First, the period for assessment is defined as one year, based on the assumption that assessment results will correspond to the fiscal years of local governments as well as the enterprises in their administrative division, which will allow for definitive comparisons of industrial and environmental statistics. For the purposes of this assessment, the year 2015 was chosen.

Second, the counting scope for assessing environmental loads is defined in accordance with the role of the local government. According to Japanese law, local governments shall autonomously and
comprehensively carry out public administration mainly for the purpose of improving the welfare of local residents. Thus, this study defines the counting scope of environmental loads as all operations carried out within the area of the administrative division and within the range for which the required statistics are as available, based on the assumption that municipalities have responsibilities providing them a broad perspective of the current circumstances throughout their divisions.

2.2. Summary of LIME2

LIME2 is an endpoint-type LCIA method developed in Japan and is based on environmental conditions and knowledge unique to Japan. LCIA systems generally comprise two processes, characterization and integration. Characterization is a process for measuring the environmental impacts of products and services throughout their life cycles on a specific impact category. Integration is a process for obtaining an assessment result for a single indicator, by integrating the environmental impacts of several impact categories. The assessment theory of LIME2 includes both of these processes and shows their assessment results as the cost of environmental impacts over a certain period with the monetary indicator Eco-index Yen (unit: Japanese yen), which is defined in this theory. The assessment framework of LIME2 is shown in Figure 1.

![LIME2 assessment framework](image)

**Figure 1. LIME2 assessment framework [11]**

The framework of LIME2 has 13 impact categories (e.g., urban air pollution and global warming), and several inventories are designated for each impact category (PM10 and CO2). Damage assessments are conducted for each impact category endpoint (respiratory illness and disaster damage). For each category endpoint, impact assessments are performed for 4 safeguard subjects: human health, social assets, biodiversity, and primary production. Finally, the results of these impact assessments are integrated into a single indicator. Through the process of integration, the assessment results of the 4 safeguard subjects are weighted by conjoint analysis based on a questionnaire survey of people’s values in Japan. Using this method, the assessment results are converted into a monetary value that can
be viewed as a reflection of Japanese environmental thought. By using this approach, the environmental loads of several inventories become comparable. The single indicator is directly obtained by multiplying the prepared factors (integration factors) with corresponding inventory data and summing these values. The calculation formula is as follows.

\[
SI = \sum_x \text{Inv}(X) \times IF(X)
\]

\(SI\): Single indicator (Eco-index yen) [yen]  
\(\text{Inv}(X)\): Inventory of substance X [kg]  
\(IF(X)\): Integration factor of substance X [yen/kg]

Other LCIA methods used around the world, such as ExternE and EPS, calculate different environmental impacts as a single indicator. However, LIME2 is the most appropriate method for the purpose of this study because of the characteristics described above, and thus this study leveraged its framework to assess municipalities in Japan.

2.3. Survey of Statistical Information

This section describes the preparation of LIME2 inventory data from statistical information in Japan. The LIME2 assessment framework comprises 13 impact categories, each of which is made up of several inventory items. However, because it was not practical to prepare all these inventory data, it was necessary to select which items to include based on a consideration of the assessment purpose, availability for information, and accuracy of the collected data. Thus, the availability of statistical information for all inventory items at the level of Japanese municipalities was surveyed before starting the study.

Table 1. LIME2 inventory data for Japanese administrative divisions

| Impact category          | Inventory (number) | Government agency                              | Indicator | Administrative unit               |
|-------------------------|--------------------|-----------------------------------------------|-----------|-----------------------------------|
| Ozone layer destruction | Various chemicals (21) | Ministry of Economy, Trade and Industry [12] | Emission amount [kg] | Municipalities                   |
| Photochemical ozone     | Various chemicals (58) | Ministry of Economy, Trade and Industry [12] | Emission amount [kg] | Municipalities                   |
| Human toxicity          | Various chemicals (99) | Ministry of Economy, Trade and Industry [12] | Emission amount [kg] | Municipalities                   |
| Biological toxicity     | Various chemicals (127) | Ministry of Economy, Trade and Industry [12] | Emission amount [kg] | Municipalities                   |
| Eutrophication          | Various chemicals (17) | Ministry of Economy, Trade and Industry [12] | Emission amount [kg] | Municipalities                   |
| Global warming          | Various chemicals (19) | Ministry of the Environment [13] | Emission amount [kg] | Municipalities                   |
| Land use                | Various types of land use (-) | Ministry of the Environment [13] | - | -                                 |
| Resource consumption    | Coal, natural gas, crude oil (3) | Ministry of Economy, Trade and Industry [14] | Consumption amount [kg] | Prefectures                      |
| Acidification           | SOx, NOx (2) | Ministry of the Environment [15] | Emission amount [kg] | Prefectures, and some municipalities |
| Atmospheric pollution   | SOx, NOx (2) | Ministry of the Environment [15] | Emission amount [kg] | Prefectures, and some municipalities |
| Waste                   | Various types of waste (-) | Ministry of the Environment [15] | - | -                                 |
| Road traffic noise      | Travel distances by type of car (-) | Ministry of the Environment [15] | - | -                                 |
| Indoor air pollution    | Various chemicals (-) | Ministry of the Environment [15] | - | -                                 |

Note: The numbers in parentheses indicate the number of inventory items for which data is available.
Publicly available statistical information that was uniformly collected or estimated by governmental agencies in Japan was used to ensure that the inventory data was reliable, verifiable, and comparable across all divisions and types of business in order to make a valid assessment of Japanese municipalities nationwide. Specifically, statistical information from the year 2015 was chosen because a comparatively large number of relevant statistical investigations were conducted that year. When data for 2015 was not available, data from the year closest to 2015 was used instead. Japan consists of 47 prefectures, which in turn consist of 1,747 municipalities. This study prioritized the uniform use of statistical information across all Japanese municipalities, with an aim to provide useful knowledge to local governments throughout the country. When statistical information at the municipal level was unavailable, it was estimated based on information collected at the prefectural level, following the method used in the previous study. In the end, the statistical information of 6 municipalities, including isolated islands, was insufficient and therefore removed from the assessments in this study. These survey results are shown in Table 1, which describes the inventory items for which data was available, the number of these inventory items, the government ministry that conducted the statistical investigation, the indicator for the assessment of municipalities in this study, and the minimum administrative unit for which data was available, according to all 13 impact categories. The statistical information for 4 impact categories (land use, waste, road traffic noise, and indoor air pollution) was not available by type of business. Thus, unlike the previous study, these four inventories were excluded from the assessments of the present study.

3. Assessment results and discussions

In this section, the environmental loads for the administrative divisions of Japanese municipalities nationwide are calculated based on the abovementioned methods, and these results are indicated with the monetary unit, the Eco-index yen. This indicator is called the damage amount on environmental assets. Additionally, this study classified industries as primary secondary, and tertiary industries, a classification system often used in Japan. Primary industries include agriculture, fishing, livestock farming, and forestry. Secondary industries include mining, construction, and manufacturing. Tertiary industries include service industries such as finance, information technology, health care, and welfare. Based on the assessment results, 5 categories were prepared: primary industries, secondary industries, tertiary industries, the residential sector, and the transportation sector. As previously mentioned, secondary industries were divided into mining, construction, and manufacturing because the total damage amount in this category was the largest of the 5 categories.

The total annual damage amount (4.63 trillion yen) by type of business in Japan is shown in Figure 2. The largest category was manufacturing (47.5%), followed by tertiary industries (25.1%), the residential sector (13.9%), and the transportation sector (11.3%). The amount per industry was 13.4

![Figure 2. Total damage amount in Japan by type of business](image-url)
**Figure 3.** Damage amount by type of business per capita and per GRP by all municipalities (upper 6 maps, per capita; lower 4 maps, per GRP)
billion yen (primary industries), 2.29 trillion yen (secondary industries), and 1.16 trillion yen (tertiary industries), and the percentages of the total were 0.3%, 49.4%, and 25.1%, respectively in turns.

The assessment results are shown in a map of Japan, in order to visualize the regionality of environmental loads nationwide. The damage amount by type of business per capita and per GRP by Japanese municipalities is shown in Figure 3. GRP is the total amount of added value for each industry in a certain division in a certain period, and it is indicated by a monetary unit. The damage amount per capita is shown for 6 categories: primary industries, construction, manufacturing, tertiary industries, the residential sector, and the transportation sector. The damage amount per GRP is shown for the 4 former categories. Here, the damage amount for all municipalities is shown so that map colors represent 10% increments of cumulative frequency distribution.

Focusing on the damage amount per capita, the results for primary industries and manufacturing clearly reflected the activities of Japanese industries nationwide. The damage amount of primary industries tended to be higher in regions where agriculture, fishing, and livestock farming is active such as Hokkaido, Japan’s northernmost island. The damage amount of construction tended to be higher in cold northern regions because buildings there require heat insulation and winterization, necessitating more materials and labor than in warmer regions. Tertiary industries are generally more active in urban areas in Japan, but the characteristic tendency of damage amount expected for tertiary industries was not observed in in this case because the population is more concentrated in urban areas. In contrast, the damage amount of tertiary industries tended to be higher in colder regions because the heating energy consumed during working hours was greater than in warmer regions. Similarly, the damage amount of the residential sector tended to be higher in colder regions, particularly in Hokkaido, because the heating energy consumed was also greater than in other areas. The damage amount of the transportation sector tended to be higher in urban areas. It was suggested that there was sufficient public transportation there, and the traffic environmental load per capita was therefore lower than in other areas.

Focusing on the damage amount per GRP, the characteristic tendency was observed in the assessment result of manufacturing. The rate tended to be higher in the Chubu region (the central part of Japan that includes Nagoya). This can be explained by the concentration of the automotive and the electronics industries in the region, and these industries contribute a large added value. It was suggested that the automotive industry produced large benefits relative to its environmental loads. Similarly, the benefits produced by the electronics industry were large relative to the unit size of its products, so the value added is larger than the environmental loads.

As above, the environmental efficiency for production was conceptualized for all Japanese municipalities based on this unique method, and it was possible to capture the regionality for the concept nationwide.

4. Conclusions

This study focused on Japanese minimum administrative divisions (municipalities) and attempted to quantify the annual environmental loads by type of business in each division by using the LCIA method LIME2. First, annual environmental impact assessments for all Japanese municipalities were conducted based on the framework of LIME2. The results revealed that the environmental damage amount for Japan was 4.63 trillion yen. Next, the damage amounts were divided by the population and GRP of each municipality. When these results were placed on a map of Japan, tendencies related to industrial activity were found.

While this study described assessments of Japanese municipalities by using the LCIA method tailored for Japan’s unique conditions, it may be more important to expand this concept to rest of the world because sustainable development is becoming a common challenge worldwide. Therefore, it will be a future task to use a global-scale LCIA method to conduct an assessment of administrative divisions in every country and to disseminate information that will help local governments around the world build a sustainable society.
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