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GIS-Based Regionalization of LCA

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Abstract

Although LCA is normally not focused on the local impacts for a product system, but when LCA is applied to other environmental system analysis tools the local impact may be important, such as the Strategic Environmental Assessment (SEA). In this study, the regionalization of LCA refers to the conversion of the results from site-generic or site-dependent LCIAs into smaller spatial units. The regionalization of LCAs is achieved by a geographic information system (GIS). GIS can easily allocate the impact into smaller spatial units through the overlay analysis of fate, exposure and effect layers.

Keywords

Life Cycle Impact Assessment; Geographic Information System; Strategic Environmental Assessment

1. Introduction

A life-cycle assessment is a technique to assess the environmental impact that is associated with all of the stages of a product's life, from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. According to the ISO 14040 (2006) and 14044 (2006) standards, a Life Cycle Assessment has four distinct phases. The first phase is "Goal and scope", which requires an explicit statement of the goal and scope of the study. It establishes the context of the study and explains how and to whom the results are to be communicated. The second phase is a "Life cycle inventory (LCI)", which involves the creation of an inventory of the flows from and to nature for a product system. Inventory flows include inputs of water, energy and raw materials, and releases to air, land and water. The third phase is a "Life cycle impact assessment (LCIA)", which evaluates the significance of any potential environmental impact, based on the LCI flow results. A classical LCIA consists of the following mandatory elements: selection of impact categories, category indicators and characterization models. In the classification stage, the inventory parameters are sorted and assigned to specific impact categories. In impact measurement, the categorized LCI flows are characterized, using one of many possible LCIA methodologies, into common equivalence units that are then summed to provide an overall impact category total. The last phase is "Interpretation", which is a systematic technique that identifies, quantifies, checks, and evaluates information from the results of the life cycle inventory and/or the life cycle impact assessment. The results of the inventory analysis and impact assessment are

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summarized during the interpretation phase.

ISO 14040 states that the mandatory steps for an LCIA are impact category selection, classification, and characterization. The characterization factors convert and combine the LCI results into representative indicators of impacts to human and ecological health. The characterization factors can be site-generic, site-dependent, and site-specific (**Table 1**) (Potting & Hauschild, 2006).

- Site-generic LCA. There is no difference in the locations of sources or receiving environment due to the lack of spatial information and the assumption of globally homogeneous effects.
- Site-dependent LCA. Some spatial information in sources and receiving environment determines the impact. Sources are typically defined at the level of countries or regions within countries (scale 50-500 km). The receiving environment is typically defined at 5 - 150 km.

Site-specific LCA. A very detailed spatial differentiation is performed by considering in sources and receiving environment at specific locations. This requires local knowledge about the fate, exposure and effect of a pollutant. The site-specific methods can be considered as the traditional modeling methods, which require a large amount of time, effort, and money.

In this study, the regionalization of LCA refers to the conversion of the results from site-generic or site-dependent LCIAs into smaller spatial units, focusing on local impact. Although LCA is normally not focused on the local impacts for a product system (Potting & Hauschild, 2006), but it is important when applied to other analysis tools such as the strategic environmental assessment (SEA). SEA is a procedural tool to facilitate early and systematic consideration of potential environmental impacts in policies, plans and programmes.

Geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. In this study, the regionalization of LCAs is achieved by a geographic information system (GIS). GIS can easily allocate the impact into smaller spatial units through the overlay analysis of fate, exposure and effect layers.

2. Material and Methods

2.1. Case Study

The study case is an incineration plant for municipal solid waste and located in Taoyuan County of Taiwan, as shown in **Figure 1**. Its neighboring townships are Dayuan Township, Zhongli City, Pingzhen City, Yangmei Township, Bade City, Daxi Township, Yingge District, Taoyuan City, Guishan Township, and Luzhu Township and their areas, populations and population densities are shown in **Table 2**. The incineration plant covers an area of 3.1 hectares. There are two furnaces in the incineration plant. The processing capacity of each furnace is 675 tons/day, and its design heat value is 2300 kcal/kg. In each year, its emissions of SO_x, NO_x, TSP, HCl, As, Cd, Cr, Pb, CO and CO_2 are 365,697.33, 684,388.69, 408,708.01, 55,465.59, 12.07, 3.12, 25.78, 57.58, 2,397.07 and 1.31×10^8 kg, respectively.

2.2. Life Cycle Impact Assessment

IMPACT 2002+ (Jolliet *et al.*, 2003) is an impact assessment methodology originally developed at the Swiss Federal Institute of Technology—Lausanne (EPFL), with current developments carried out by the same team of researchers now under the name of ecointesys-life cycle systems (Lausanne). The present methodology proposes a feasible implementation of a combined midpoint/damage approach, linking all types of life cycle inventory results (elementary flows and other interventions) via 14 midpoint categories to four damage categories, as

Table 1. The spatial resolution for spatial differentiation in LCA.

Spatial differentiation	Source	Receiving environment
Site-generic	• Globe	• Globe
Site-dependent	• Countries • Regions within countries • 50 - 500 km	• 5 - 150 km
Site-specific	• At specific locations	• <10 km

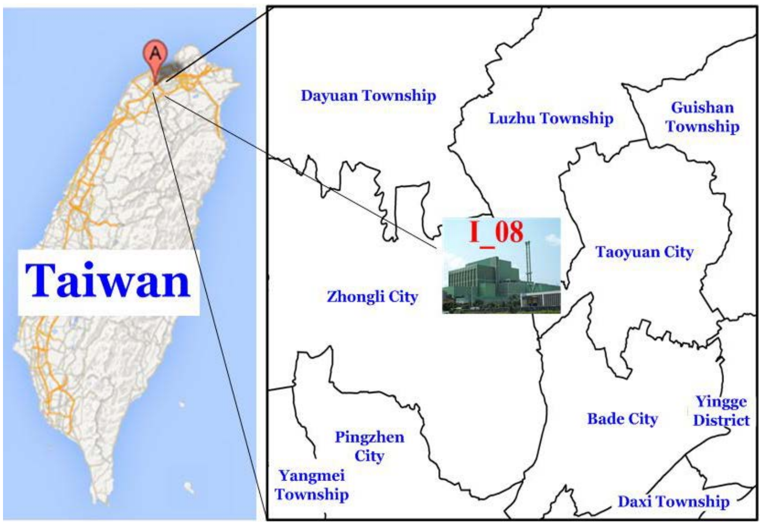

Figure 1. An incineration plant for municipal solid waste (Taiwan).

Table 2. The neighboring townships of the case study and their areas, populations and population densities.

Township	Area (m^2)	Population	Population density
Dayuan Township	87,097,943	82,495	0.000947
Zhongli City	76,111,210	375,738	0.004937
Pingzhen City	43,447,999	209,189	0.004815
Yangmei Township	89,645,651	153,992	0.001718
Bade City	33,779,044	178,670	0.005289
Daxi Township	105,166,183	91,916	0.000874
Yingge District	21,892,512	88,122	0.004025
Taoyuan City	34,365,351	412,859	0.012014
Guishan Township	71,434,193	139,478	0.001953
Luzhu Township	74,576,566	146,207	0.001960

shown in **Figure 2**. Damages to Human Health are expressed as DALY (Disability Adjusted Life Years). Damages to Ecosystem Quality are expressed as the percentage of species that have disappeared in a certain area due to the environmental load (PDF).

2.3. GIS-Based Regionalization of LCA

The regionalization of a LCA has been addressed in literature (Jolliet, *et al.*, 2003; Nansai, *et al.*, 2005; Mutel & Hellweg, 2009; Mutel, *et al.*, 2012; Mutel, *et al.*, 2013). But the regionalization of a LCA result is defined completely differently. It depends upon some relevant factors, which are categorized into three groups: fate-, exposure- and effect-related. The fate factors refer the factors influence the transferring and distribution of a pollutant, including geographical conditions, meteorological conditions, the background level, etc. The exposure factors refer to the conditions involving the existence of environmental impact receptors, such as human, animal, or a protective zone. The effect factors refer to the sensitivity of the receptors to the pollutant. These factors are geography-related and then can be displayed on the GIS layers, as shown in **Figure 3**.

The impact score is calculated by the exposure and effect factors, such as Impact $\text{Score}_{ijk} = \text{Fate}_i \times \text{Exposure}_j \times \text{Effect}_k$. Finally, the allocation of a LCIA result for each spatial unit (ijk) is based on the impact score.

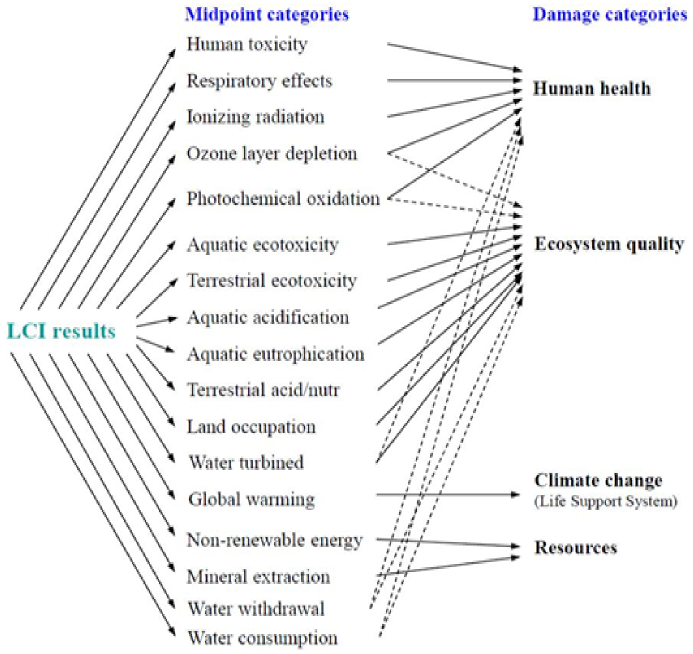

Figure 2. Framework of IMPACT 2002+ (Jolliet, *et al.*, 2003).

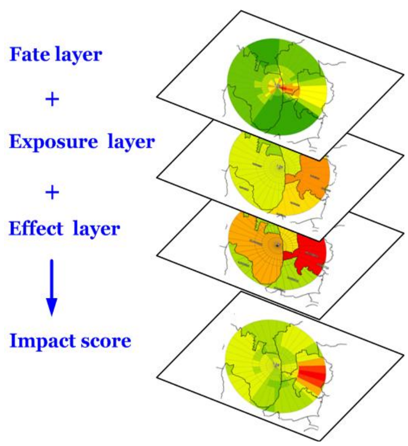

Figure 3. Impact score: the combination of fate, exposure and effect factors.

3. Results and Discussion

3.1. Fate Layer

Fate analysis links an emission (expressed as mass) to a temporary change in concentration. Firstly, the dispersion of NO_x emission is carried by the Gaussian diffusion model, as shown in **Figure 4**. For simplification, the oval in **Figure 4** is approximately covered into a circular sector, as shown in **Figure 5**.

Secondly, the surface wind rose is considered because the transportation of NO_x emission is influenced by the meteorological condition, as shown in **Figure 6**.

Thirdly, the combination of **Figure 5** and **Figure 6** is a probability of affected area, as shown in **Figure 7**.

3.2. Exposure Layer

Exposure analysis links this temporary concentration to a dose. For the respiratory effect, the receptors are human. The population density will influence the allocation of the LCIA result, which means higher population

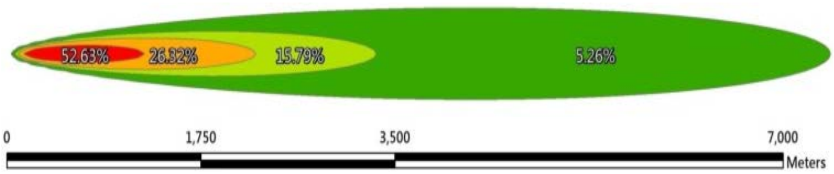

Figure 4. The dispersion of NO_x emission using the Gaussian diffusion model.

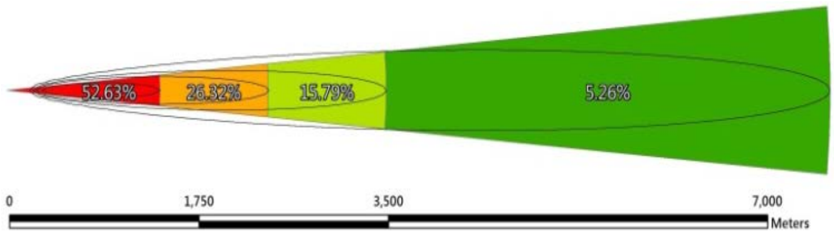

Figure 5. A circular sector to approximately represent the dispersion of NO_x emission.

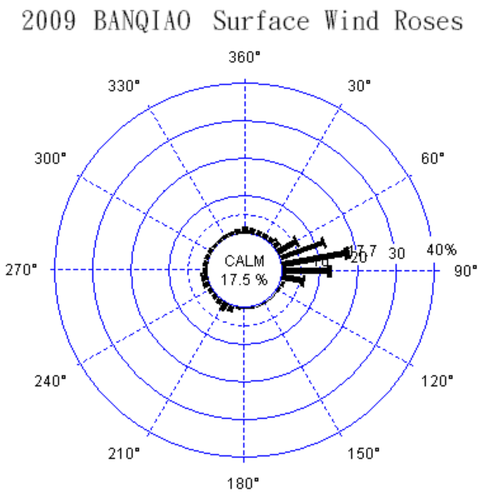

Figure 6. The surface wind rose.

density should be obtained more DALY. The population density of the case study is shown in **Figure 8**.

3.3. Combination

Effect analysis links the dose to a number of health effects, like the number and types of cancers. But in this study, effect analysis is neglected in the procedure of the regionalization. The impact scores for DALY and ADALY (Average DALY, DALY per person) caused by the respiratory effects are calculated, their results are shown in **Figures 9-12**. **Figure 9** represents the distribution of the DALY caused by respiratory effect; **Figure 10** refers to the distribution of the DALY over townships; and **Figure 11** shows the distribution of the ADALY caused by respiratory effect.

4. Conclusion

This study proposed a novel concept—the regionalization of the existing LCA methods. Although LCA is normally not focused on the local impacts for a product system, but it is important when applied to the strategic environmental assessment (SEA). This study uses a geographic information system (GIS) to regionalize LCAs because it can easily allocate the impact into smaller spatial units through the overlay analysis of fate, exposure and effect layers. The case study shows that the method can appropriately allocate the DALY caused by respiratory effect into eight neighboring townships, based on their meteorological conditions and population density.

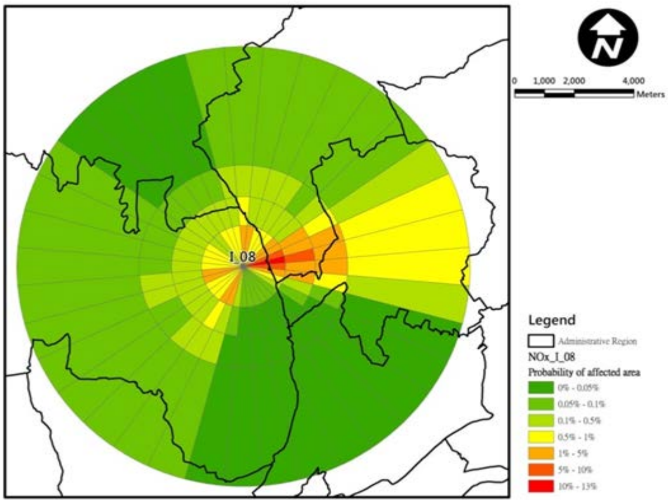

Figure 7. Probability of affected area.

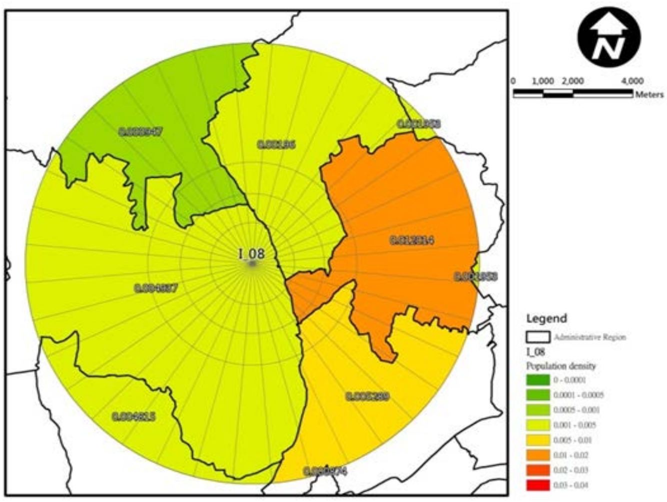

Figure 8. Population density in the affected area.

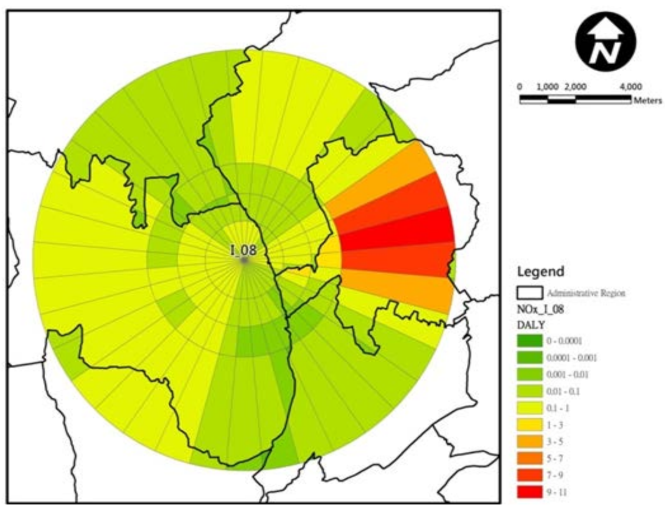

Figure 9. The distribution of the DALY caused by respiratory effect.

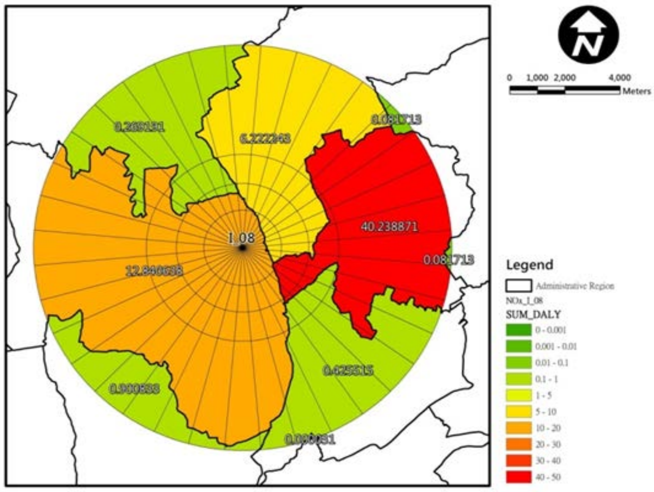

Figure 10. The distribution of the DALY over townships.

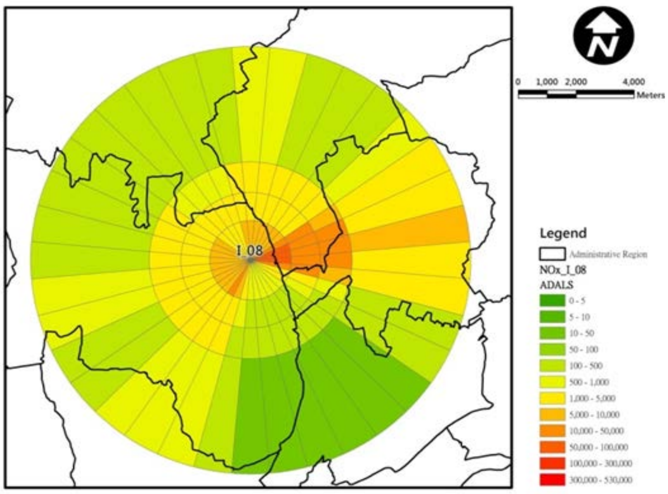

Figure 11. The distribution of the ADALY caused by respiratory effect.

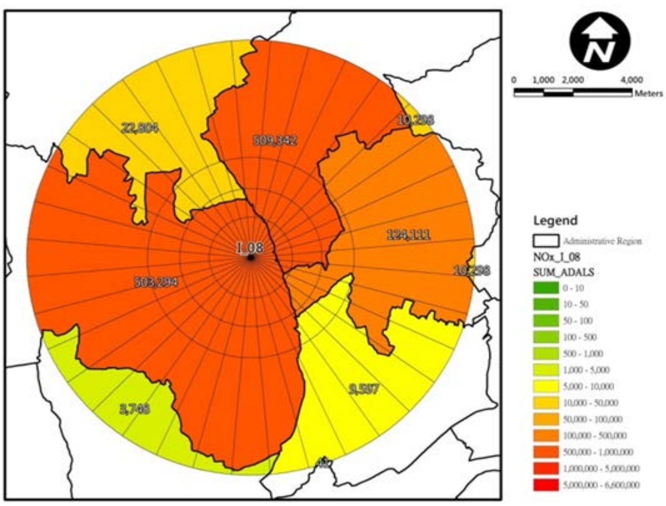

Figure 12. The distribution of the ADALY over townships.

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