Life cycle assessment and interpretation of municipal solid waste management
according to midpoint and endpoint approaches
（ミットポイントとエンドポイントアプローチによる
都市廃棄物管理のライフサイクルアセスメントとその解析）

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Integrated Municipal Solid Waste (MSW) management is to reduce the amount of waste generated and manage the waste systems in a sustainable way by minimizing environmental burdens, as well as maximizing energy and resource recoveries.

A sustainable MSW system needs to considerate following three aspects, environmental assessment, economic efficiency and social preferences.

This study aims to:

• Analyze the **characteristics of MSW** according to the inhabitant density of population and the business concentration in 25 districts in Seoul;

• Assess **avoided impacts** on heat energy recovery of four incineration plants in residential and commercial areas in Seoul;

• Evaluate waste management systems through **midpoint and endpoint** approaches to life cycle impact assessment (LCIA) according to **global, regional and local spatial scales**; and

• Define **social preferences** based on midpoint and endpoint interpretations of LCA.

In the assessment of MSW systems, the change of **MSW characteristics** has become a key factor depending on MSW treatment and disposal options. The change of MSW composition such as food waste or plastics is influencing to landfill gas emissions and heating value during incineration. In Seoul, 11,170 ton per day of MSW is generated from 10.3million population in 25 districts in 2005. Of the total MSW, 82% was generated from households and small-scale businesses and 18% was generated from large business sectors. The amount of residential waste per day in Seoul is in average 0.886kg per capita, which tends to increase from 0.815 to 1.523 kg per capita according to lower density of inhabitants. It seems to be affected by floating population who visit small-scale businesses. There were clear trends of increasing the amounts of food waste and combustible plastics according to lower inhabitant densities. The amount of commercial waste per day in Seoul is 0.547 kg per worker, which tends to increase from 0.332 to 0.703 kg per capita according to higher business

concentrations. The bigger businesses seem to produce larger commercial wastes per worker because of many visitors. There the increases of the percentages of food waste in total commercial wastes according to lower business concentration, not consistent with the trends of the amounts of food waste. There were clear trends of decreasing the amounts of combustible and recyclable plastics according to lower business concentration.

The issue of **avoided impact assessment** has grown in importance in light of recent researches. 'The best available MSW systems' need to create environmental benefits derived from the avoided environmental impacts by resource and energy recoveries, as well as cost benefits. Avoided CO_2 emissions mean CO_2 emissions avoided from renewable energy, in this study, which is heat energy generated by combusting waste instead of LNG for the district heating system. The values of heat energy generated from four incineration plants in very residential, residential, commercial and very commercial areas are 8.6, 11.2, 12 and 11MJ/kg respectively. The scenarios studied here look at the current system and the full capacity of incineration plants in very residential, residential, commercial and very commercial areas. The avoided CO_2 emissions were estimated as respectively 321, 452, 492 and 443 kg CO_2/ton-mixed waste in very residential, residential, commercial and very commercial areas. It is concluded that the plant in the commercial area with many office-type businesses can save CO_2 most efficiently in terms of heat energy recovery by combusting 1 kg of waste. Based on the avoided CO_2 assessment, the saved CO_2 emission from 4 waste-to-energy plants with full-scale operation is 444 Gg CO_2. This amount is equivalent to 3.7% of the volume of CO_2 emitted to produce gas in Seoul. This finding suggests that 51,421 households can be provided with heat energy equivalent to 489,721 Nm^3 LNG from the full-operation system. Avoided CO_2 assessment in this study has a number of implications for future practice.

It has been considered that results from an **endpoint approach** in LCIA indicate lower uncertainty in the interpretation compared to a **midpoint approach**. The problems with this endpoint approach, however, are that it fails to take all potential damages into account, meaning this approach may estimate only characterized damages defined clearly, as well as double counting damages. So far there has been little discussion about the differing interpretation between midpoint and endpoint LCIA results on the same systems. This paper focuses on LCIA of MSW systems according to midpoint and endpoint approaches, using LIME (Life-cycle Impact assessment Method based on Endpoint Modeling-1, 2006 ver.). Considering global and site-dependent factors, the environmental impact categories were divided into **global, regional and local impacts**. The scenarios were selected based on a mix of technologies applicable to urban areas followed by hierarchy of waste management. Each scenario includes a number of waste treatment and disposal options. The main system of scenario 1 is a landfill system for all MSW materials avoiding emissions by 50 percent of

landfill gas recovery. Scenario 2 involves a landfill process of mixed waste and reprocessing processes of recyclable materials, with avoided impacts of landfill gas recovery and virgin material savings. Biological treatments of food waste were introduced in scenario 3, including landfill systems and material recovery with same conditions of scenario 2. The biological treatments studied here are divided into the composting process of commercial food residuals and the biogasification process of household food wastes. Scenario 4 is including the same systems except replacing landfill fraction to incineration process. This study introduces two kinds of source-oriented environmental impacts or damages, meaning MSW **system** emissions and **avoided** emissions through both midpoint and endpoint approaches. The results of LCIA are calculated according to a 'Net emission' approach: 'Total emissions of each scenario' minus 'Avoided emissions thanks to the use of the energy and material output of that scenario'.

This study evaluated LCIA on separated **midpoints** for each process and holistic systems of each scenario. In the comparison according to waste composition changes in landfill systems, this study has shown that all separated midpoints were strongly responding on biodegradable fractions in the landfill process of each scenario. The evaluations of alternative MSW managements of recyclable materials, e.g. a landfill practice and material recycling, carried out and suggest that in general material recycling is a good practice for recyclables considering avoided impacts. The evaluation of each scenario is based on the results from LCIA 9 midpoints by grouping impact categories from global, regional and local impacts. Scenario 1 using landfill is the worst performing in the aspect of global impacts (global warming and resource consumption) and regional impacts (acidification, human toxicity and eco-toxicity), with all but one of eutrophication, whereas effectively performing on local impacts. From local impacts (photochemical oxidant creation and landfill volume) point of view, scenario 4 using incineration, material recycling and biological treatment is the poorest performing, including avoided impacts. In terms of all impacts except global warming and waste, scenario 2 using landfill and material recycling is evaluated as an effective system.

Though endpoint approach, this study evaluates the separated **endpoints** such as human health, social asset, biodiversity and primary plant production caused by 11 environmental impact categories. The evaluation of each scenario is based on the results of LCIA by grouping damages from global, region and local impacts. In this **human health** damage analysis, various damages are caused by global impacts from global warming (zero damage from ozone layer depletion); regional impacts from human toxicity; and local impacts from photochemical oxidation creation and urban air pollution. This study suggests that there is no or less human health damage offset by avoided impacts in terms of regional and local scales, because safeguards affected by on-site or off-site emissions would be different. **Social asset** damages from global impacts are caused by global

warming (zero damage from ozone layer depletion) and resource consumption; regional impacts by acidification and eutrophication; and local impacts by photochemical oxidation creation. As thinking of global scales in social assets, it is more meaningful to assess net social assets as wide-range environmental issues. **Biodiversity** damages from global impacts are caused by resource consumption, regional impacts by eco-toxicity and local impacts by land use and waste. There are clear outcomes of indicating all scenarios influenced by regional and local impacts mainly. It is possible to consider that the offset by avoided impacts in terms of regional and local scales are less likely to occur on the basis of on-site boundary. In this **primary plant production** damage analysis, various damages are assessed in terms of global impacts from resource consumption (zero damage from ozone layer depletion), regional impacts from acidification and local impacts from photochemical oxidation creation and land use and waste. Over all damages of primary plant production were influenced by global and local impacts mainly. To offset those damages from local impacts such as photochemical oxidation creation and land use and waste, two different safeguards located on-site and off-site limited it. As damages analysis by global impacts in the net emissions, scenario 1 is the poorest performing. Out of all damages by regional and local impacts from MSW systems, scenario 4 is the worst performing in terms of human health and social asset, while scenario 1 in terms of biodiversity and primary plant production. In terms of all damages regardless source-oriented emissions, scenario 2 using landfill and material recycling is evaluated as an effective system. In monetization analysis, comparing each scenario showed that scenario 2 is 'the best available system', indicating 9.2 USD saving per ton-waste and considering MSW system and avoided emissions and integrating all endpoints.

Prior to the introduction of the new policy of MSW management, government should hold meetings with stakeholders and consider all possible environmental impacts (e.g. global, regional and local impacts). The social groups in this study are divided into three groups, individualist, hierarchist and egalitarian responding to environmental conflicts. A questionnaire was made to investigate the **social preferences** of solid waste management linked to two points of view for decision-making according to midpoint (environmental impacts) and endpoint (damage) approaches. 1,000 metropolitans in Korea answered these Internet surveys including 31 questions. In this survey, 511 men and 489 women answered this questionnaire with 5 % under age 20, 34 % 20s, 35 % 30s, 16 % 40s and 10 % over 50 years of age. 284 respondents answered 'Seeing MSW facilities in my daily life', meaning the MSW facilities located nearby their houses, working places or schools. Many people (627 respondents) referred to bad image to MSW facilities due to bad view and risks from MSW facilities. 517 respondents chose global impacts as the most important environmental impact, followed by regional impacts (338 respondents) and local impacts (145 respondents). And, in the question regarding the most important safeguard, most respondents chose equally the damages of human health (288 respondents), social asset (310 respondents) and primary plant production (268

respondents), while small respondents chose the damage of biodiversity (134 respondents). This survey revealed that the relative comparison of importance among four endpoints categories different from LIME study reflecting Japan cultures. What is interesting in this survey is that 691 respondents of those who answered choosing social groups belong to the hierarchist group, while 135 respondents answered the individualist group and 174 respondents answered egalitarian group. After choosing a scenario without any information of environmental impacts or damages, 5 questions (linked to LCIA results from midpoints, human health, social asset, biodiversity and primary plant production) continued for social preference of each scenario. Attitudes toward choosing scenarios were changed responding to given information of scenarios, environmental impacts or damages. This survey revealed that almost half (497 persons) of total respondents chose scenario 4 as their preferences, consistent with the new policy of Seoul Authority to increase the incineration rates. The trends of preferable scenarios are related to 6 factors, e.g. the environmental problems on global, regional and local scales, MSW system and avoided emissions and just preferable scenario. Questionnaire was made to investigate the social preferences of solid waste systems depending on social groups. Totally scenario 4 is the most preferable for the individualist and egalitarian groups, while scenario 3 is the most preferable for the hierarchist group. Final question was to find a preferable decision-making tool between midpoint and endpoint approaches. Over two-thirds of the participants (68%) said that midpoint approach is good to evaluate environmental systems. The most striking finding to emerge from the survey is that this finding is not consistent with those of other studies, which suggested that the endpoint approach is suitable for decision support involving many different stakeholders with a low level of environmental expertise. This finding has important implications for developing decision-making tools in midpoint and endpoint approaches.

As the introduction of the new policy of MSW management, LCA is an indispensable step for a decision-making process based on social preference. A key advantage of an endpoint approach is that the results of damages from global, regional and local impacts could be compared by normalization and integration steps, while detailed results on separated midpoints support process monitoring and optimization. However this survey revealed that the relative comparison of importance among four endpoints is changing according to attitudes of different individuals or social groups and different from LIME study reflecting Japan cultures. Further researches regarding site-dependent impact and different source-oriented emissions are strongly recommended, because there is a need to develop methodologies better adapted to cover a wider range of situation and environmental and social conditions, especially for the MSW system assessment. The results for this study will supplement the evidence base that will inform the urban municipal solid waste management strategy.