Life cycle assessment of MSW-to-energy schemes in Thailand

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Abstract

Life cycle assessment was performed to evaluate environmental impacts of two municipal solid waste (MSW) to energy schemes currently practiced in Thailand: incineration and anaerobic digestion. Potential impacts such as global warming, acidification, stratospheric ozone depletion, and photo-oxidant formation were avoided due to net electricity production and also fertilizer production as by-products from the anaerobic digestion scheme. In addition, the anaerobic digestion resulted in the higher net energy output compared to the incineration scheme. However, the incineration had less potential impact for nutrient enrichment. The LCA results were also useful in determining where the improvements could be made for both the schemes. In order to adopt a sustainable waste management system elsewhere in the country, decision makers may need to consider a combination of techniques, or an integrated method of management. LCA could serve as an invaluable tool for such an analysis.

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1. Introduction

Municipal solid waste (MSW) in Thailand has increased steadily during the last decade. About 38,000 ton/day of refuse was collected across the country in 2002 compared to 29,000 ton/day in 1992\textsuperscript{[1]}. In densely populated cities such as Bangkok, MSW generation has increased from 3000 ton/day in 1985 to 9000 ton/day in 2001 and is expected to reach beyond 18,000 ton/day in 2015\textsuperscript{[2]}.

Conventional handling of MSW poses serious environmental and public health concerns as a large number of the landfills in Thailand are not well-engineered. For example, surface water around the On-nooch disposal site, the Bangkok Metropolitan Administration’s (BMA) biggest solid waste disposal site, was shown to be polluted by leachate. Organic matter, nitrogen and heavy metals were detected at higher levels than allowable\textsuperscript{[3]}. Due to these problems, sound and sustainable methods of solid waste management have been sought by central and regional policy makers.

Waste-to-energy schemes which provide energy in the forms of heat and/or electricity as by-products are regarded sustainable. Energy obtained from waste-to-energy plants in terms of combustion efficiency is equivalent to that gained from coal-fired plants\textsuperscript{[4]}. However, it is considered cleaner with regard to environmental emissions. Less emissions of CO\textsubscript{2}, SO\textsubscript{2}, NO\textsubscript{X} are anticipated compared with those generated from coal or fossil fuel-fired power plants. However, absolute environmental impacts from these waste-to-energy plants must be thoroughly investigated. In Thailand, power production partly relies on imported coal, lignite, natural gas, and crude oil. Emissions from power plants are the major source of air pollutants in the country\textsuperscript{[5]}. According to the 7th National Economics and Social Development Plan, production of electricity from renewable sources is being promoted. Energy sources such as biomass, solar systems, wind, and municipal solid waste are considered as potential resources for the future development\textsuperscript{[6]}.

Currently, there are two municipal solid waste-to-energy schemes adopted in Thailand: incineration with electricity...
recovery and anaerobic digestion in which electricity and fertilizer are produced. To be promoted as effective methods of solid waste management in terms of environmental soundness and energy saving, a quantitative assessment needs to be performed. In addition, comparison between the two schemes in terms of efficiency (resource and energy use) and environmental friendliness should be determined to provide enough information for the policy makers in any decision made concerning the desired MSW management option. In this study, life cycle assessment (LCA) was employed as the tool for environmental analysis.

2. Methodology

LCA methodology according to the ISO 14040-1 as outlined in Wenzel et al. [7] was used.

2.1. Goal and scope definition

The objective of this study was to compare performance of two MSW-to-energy schemes, incineration and anaerobic digestion, in terms of environmental impacts and energy balance. The waste was taken as input to the system and not followed upstream (waste collection and transportation). This is because equal amounts of waste of the same composition were treated by both incineration and anaerobic digestion; hence all the environmental burdens for the upstream processes would be common to both. Characteristics of MSW for this study as shown in Table 1 were after sorting at the incineration plant.

The functional unit was 1 ton of MSW managed. For incineration, a plant of 250 ton/day capacity, grate type stoker, and equipped with bag filter as the Air Pollution Control Unit, was studied. For anaerobic digestion, a plant of 50 ton/day capacity was considered. Both the schemes recovered electricity. There was no utilisation of heat. System boundaries for the incineration scheme (Fig. 1) include waste combustion, lime production, air pollution control, steam and electricity production, and disposal of ash to landfill.

For the anaerobic digestion scheme, processes of separation, slurry preparation, anaerobic digestion, biogas production, fertilizer production, electricity production, and disposal of solid residues to landfill are included as shown in Fig. 2. Transportation, construction and maintenance of the plants, and recycling were not included in the study. The following key assumptions were made: (1) For incineration, all the wastes were combusted (mass burn). Ash and other solid residues such as metals were disposed off in landfill. (2) Anaerobically digested components of MSW such as paper, food, and yard waste were included in anaerobic digestion scheme. The rest was disposed off in landfill. (3) Organic humus that was obtained from anaerobic digestion scheme was equivalent to chemical fertilizers both in quality and quantity.

Credits were provided to the incineration scheme for avoided electricity production, and anaerobic digestion for avoided electricity and fertilizer production. (4) Conventional production of electricity by the Electricity Generation Authority of Thailand (EGAT) — natural gas, coal and oil based — is assumed to be displaced by the electricity produced in both schemes. Avoided emissions from the production of electricity for MSW incineration, and electricity and fertilizer for MSW anaerobic digestion, were included in the calculation of impact potentials using the principle of system expansion [8,9].

2.2. Inventory analysis

Emissions to air, water, and soil, resources and materials used, and energy consumption were calculated and expressed as per functional unit. Data such as the amount of resources used and emissions (in case of incineration) were obtained from the incineration plant at Phuket in South Thailand. For anaerobic digestion, since the plant (the only one in the country) was still under construction at the time of the study, some data were obtained from design documents and emissions were calculated using emission factors from Eleazer et al. [10] and White et al. [11]. Inventory of conventional electricity production in the country was obtained from TEI (coal — 17.1%, natural gas — 60.7%, heavy oil — 1.8%, hydro — 3.7%, and unspecified — 16.7%) [12]. Other data were obtained from the database of the software, SimaPro 5.0 (Pre Consultants, the Netherlands).

2.3. Impact assessment

The environmental impact categories investigated were global warming, acidification, nutrient enrichment, stratospheric ozone depletion, photo-oxidant formation, impacts from heavy metals, solid waste to landfill, and consumption of energy resources. The impact assessment was carried out until the characterisation step. There was no normalisation or weighing of the impacts. SimaPro 5.0 with the Eco-indicator 95 impact assessment methodology was used to calculate the potential environmental impacts.
3. Results

For interpreting the results from the impact assessment step, the MSW incineration scheme was divided into the sub-processes — combustion, diesel production, lime production, and electricity production. The MSW anaerobic digestion scheme was divided into the sub-processes — digestion, electricity production, and fertilizer production. For the MSW anaerobic digestion scheme, avoided impacts resulted from the production of electricity and fertilizer. These avoided impacts could offset impacts from the process of anaerobic digestion itself (which were small) resulting in large negative total impacts for most of the impact categories considered. For the MSW incineration scheme, although there was electricity production, avoided impacts from this activity could not offset many of the impacts from the process of incineration itself. The production and consumption of lime and diesel, included in the system boundary, were shown to have a major contribution to the impacts. Since the MSW had high moisture content, fuel such as diesel was needed for burning the waste.
Although, this study did not include impacts from transportation, construction and maintenance of the plants, and recycling, the LCA results are sufficiently useful for policy makers. From initial calculations, it was seen that impacts from these activities, particularly transportation, contributed less to the whole impacts. This was consistent with the results of Ross and Evans [13]. Moreover, since recycling activity in Thailand has not been systematic, the results might not be representative of the situation in the future. It would thus be an interesting consideration for further research, especially since recycling is being promoted and may be done systematically and on a large scale in the future. The detailed interpretation of each of the impact categories considered in this study is presented below. The numerical results are presented in Tables 2 and 3.

3.1. Global warming

For the incineration scheme, the combustion process generated more greenhouse gases resulting in the high impact expressed as kg CO₂ equivalent. The avoided global warming impact from electricity production could not offset the gross impact resulting in a net positive impact. Generally, combustion of MSW generates both biomass CO₂ and fossil CO₂. Biomass CO₂ is higher because of the higher fraction of organic waste such as food waste, yard waste, and paper than plastics that come from fossil fuel. This fraction does not contribute to global warming in contrast to fossil CO₂ since it is part of the global carbon cycle. Although the combustion of biomass helps reduce the generation of greenhouse gases in particular of CO₂ during the combustion process other fuels, for instance diesel, are used to help burning of MSW because it has high moisture content. This is the case for MSW incineration in Thailand where the moisture content of 40–60% is present in the waste. The largest fraction of the MSW is food waste, which has moisture content of 69% (the figure used in this study). Burning of this waste without using other fuel is difficult. Since the incineration is a mass burn type, separation of wastes according to their heating values and moisture content and burning with suitable proportion should improve the combustion and reduce the use of other fuels.

Another approach could be to dry the waste having high moisture content before incineration, perhaps by heat which is generated from the combustion and currently not being utilized. However, investigations should be performed to ensure that there is no further impact from energy and resource use from such heat utilization.

For the anaerobic digestion scheme, the negative global warming impact means that the global warming potential avoided due to both fertilizer and electricity productions was greater than that produced by the anaerobic digestion activities. Thus, MSW anaerobic digestion is preferable to incineration in terms of global warming potential.

3.2. Acidification

Acid gases such as SO₃, NOₓ, HF, and HCl emitted from incineration of MSW resulted in the acidification potential which was not significantly offset by the electricity production. For anaerobic digestion, acidification potential produced by the anaerobic digestion activities was very small and thus easily offset by the avoided emissions due to fertilizer and electricity production. The avoided emissions due to fertilizer production were almost four times that of electricity production.

3.3. Nutrient enrichment

Anaerobic digestion was seen to have more potential for nutrient enrichment than incineration because of the high ammonia emission to water. The avoided impact from fertilizer production could not offset the gross impact. For incineration, gases such as NOₓ from waste combustion contributed much of the impact.

3.4. Photo-oxidant formation

Diesel production and to a lesser extent, lime production in incineration scheme contributed most to photo-oxidant formation. However, production of electricity completely offset the total impact. In anaerobic digestion scheme, similarly, the net negative impact resulted from the avoided impact primarily from electricity production. Though the photo-oxidant formation potential of both schemes is negative, anaerobic digestion performs even better than incineration.

**Table 2**

Impact assessment results for MSW incineration

<table>
<thead>
<tr>
<th>Impact category</th>
<th>Total impact</th>
<th>Combustion</th>
<th>Diesel production</th>
<th>Lime production</th>
<th>Electricity production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global warming (kg CO₂ eq.)</td>
<td>273</td>
<td>307</td>
<td>0.594</td>
<td>14.3</td>
<td>−48.4</td>
</tr>
<tr>
<td>Acidification (kg SO₂ eq.)</td>
<td>2.37</td>
<td>2.54</td>
<td>0.00491</td>
<td>0.0291</td>
<td>−0.207</td>
</tr>
<tr>
<td>Nutrient enrichment (kg PO₄ eq.)</td>
<td>0.354</td>
<td>0.372</td>
<td>0.000433</td>
<td>0.0015</td>
<td>−0.0202</td>
</tr>
<tr>
<td>Photo-oxidant formation (kg CH₄ eq.)</td>
<td>−0.00826</td>
<td>—</td>
<td>0.00391</td>
<td>0.00111</td>
<td>−0.0133</td>
</tr>
<tr>
<td>Stratospheric ozone depletion (kg CFC11 eq.)</td>
<td>−3 × 10⁻⁶</td>
<td>—</td>
<td>7.22 × 10⁻⁶</td>
<td>1.1 × 10⁻⁶</td>
<td>−1.1 × 10⁻⁵</td>
</tr>
<tr>
<td>Heavy metals (kg Pb eq.)</td>
<td>3.04 × 10⁻⁵</td>
<td>1.18 × 10⁻⁵</td>
<td>6.72 × 10⁻⁶</td>
<td>4.79 × 10⁻⁵</td>
<td>−3.6 × 10⁻⁵</td>
</tr>
<tr>
<td>Consumption of energy resources (MJ LHV)</td>
<td>−563</td>
<td>—</td>
<td>53.2</td>
<td>65</td>
<td>−681</td>
</tr>
<tr>
<td>Generation of solid waste to landfill (kg)</td>
<td>582</td>
<td>582</td>
<td>—</td>
<td>—</td>
<td>−0.0363</td>
</tr>
</tbody>
</table>
### 3.5. Stratospheric ozone depletion

There is no emission of ozone depleting substances from incineration of MSW and small amounts from diesel and lime production are offset by electricity production. In the case of anaerobic digestion too, there is no emission of ozone depleting substances from the direct activities. The avoided impacts are mainly from electricity production. For this case too, anaerobic digestion performs even better than incineration.

### 3.6. Impacts from heavy metals

For the incineration scheme, most of the impacts resulted from the lime production process. The combustion itself also contributed to the impact but only about 20% of that of the lime production process. The avoided impact due to electricity production offset about 60% of the gross impact resulting in a relatively small net positive value. For anaerobic digestion, the credit for fertilizer production resulted in net negative impacts.

### 3.7. Consumption of energy resources

When the consumption of all energy resources during the whole life cycles of the two schemes was determined, it was seen that the incineration of MSW saved less energy resources than the anaerobic digestion (563 MJ versus 3580 MJ), although both schemes performed well in that there were net energy resource savings. Energy resources consumed by lime and diesel productions reduced the savings due to electricity production by about 10% each. In anaerobic digestion, higher energy saving resulted from the production of fertilizer (70%) and to a lesser extent, from the production of electricity.

### 3.8. Generation of solid waste to landfill

MSW incineration generated more solid residues to landfill than anaerobic digestion. Ash generation accounted 582 kg per ton of MSW incinerated. The ash came from the waste itself as also from the lime that was used in the APC unit. In anaerobic digestion, solid residues resulted from the rest of MSW fraction that could not be digested at first such as plastics, metals, rubber/leather, and glass. These wastes were expected to be disposed off in the landfill following the system boundaries and assumptions made. No recycling activity was considered.

### 4. Conclusions

This study considered LCA of MSW-to-energy schemes in Thailand. Environmental impacts and energy balance were determined in a life cycle perspective. The results showed that MSW anaerobic digestion was preferable to incineration. This was partly because more than 60% of the waste is biodegradable and thus suitable for anaerobic digestion. Also, the wet nature of the waste makes direct combustion difficult. There were hot spots in both the schemes determined by the results that could be improved such as the lime production and in the incineration which contributed the majority of the impacts, and the process of anaerobic digestion that contributed to nutrient enrichment. Replacement of lime by other materials or methods that contribute less impact should be considered. For anaerobic digestion, emissions of substances to water that contribute nutrient enrichment should be addressed. However, it must be emphasized that the results of the study could be different if recycling is introduced. This is especially true for the case of anaerobic digestion where the non-biodegradable fraction of the waste is assumed to be deposited in the landfill.

The application of LCA proved to be useful for the study. Sound information and conclusions can be drawn to determine the optimum option of MSW management by policy makers provided several possible scenarios are compared. In addition, the assessment of integrated waste management in which several methods of treatment are adopted in a single scenario have been seen to be more effective in terms of energy saving and environmental friendliness [14]. However, it must be noted that the results of such a study depend on the MSW characteristics, level of sorting, recycling and the technology used. Hence, the results cannot be applied universally to any place for comparing even the same two technologies and separate evaluations must be made. But the methodological framework is useful for such evaluations.

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References


