Asian J. Energy Environ., Vol. 9, Issue 1 and 2, (2008), pp. 39-63

Environmental Perspective on Municipal Solid Waste Management System in Phuket

C. Liamsanguan[1,2] and S. H. Gheewala[2,*]

[1] Faculty of Industrial Technology and Management,
King Mongkut's Institute of Technology North Bangkok,
Prachinburi, Thailand
[2] The Joint Graduate School of Energy and Environment,
King Mongkut's University of Technology Thonburi, Bangkok, Thailand
*Corresponding author: Shabbir_g@jgsee.kmutt.ac.th

Abstract: Continually increasing amount of municipal solid waste (MSW) and the limited capacity of the existing waste management system are serious problems that Phuket municipality must deal with. The optimal waste management system should be adopted. Explicit evaluation on environmental performance of the existing waste management system should be performed ahead of decision making with respect to planning and optimizing improvements or strategies. The overall goal of this study is to evaluate the environmental performance and identify critical factors relating to the environmental performance of the existing waste management system in Phuket. Life cycle assessment (LCA) is employed as the evaluation tool. The result shows that landfilling contributes the highest potentials to global warming and photochemical ozone formation due to methane emitted from waste degradation. Besides landfilling, incineration plays a major role in contributing to the global warming potential due to the emission of fossil carbon dioxide from plastic burning. Nitrogen dioxide from combustion process is a critical factor contributing to acidification and nutrient enrichment. The study suggests the separation of plastic fractions and wet feedstocks from the waste stream to be incinerated as a first priority. Source separation, landfill gas recovery and introduction of de-NO_x equipment should also be considered.

Keywords: Environmental Evaluation, Decision Making, Life Cycle Assessment, Municipal Solid Waste, Policy.

1. INTRODUCTION

Phuket is an island province in the south of Thailand. It stretches 49 km from north to south and 19 km from east to west with the total area of 570 sq.km. With beautiful beaches along the western and southern parts of the island, Phuket is a major tourist attraction.

MSW in Phuket is collected and transported by trucks to the treatment and disposal center. It is weighed and instantly separated based on source and characteristics of the waste to be managed by three methods – incineration, recycling and landfilling. Of the total MSW collected, an estimated 71% is sent to the incinerator, 26% landfilled, and 3% sorted and recovered for recycling.

In 2004, MSW collected from communities in Phuket was about 364 tons/day, tourism activities being an important factor. Phuket MSW management is currently in a critical condition because of the continually increasing amount of MSW whereas the capacity of incineration system is limited at 250 tons/day along with an ineffective operation of the sorting plant and the limited area of landfill site. Besides reducing amount of waste generation, the optimal waste management system should be adopted. Explicit evaluation on environmental performance of the existing waste management system should be performed ahead of decision making with respect to planning and optimizing improvements or strategies. The overall goal of this study is to evaluate the environmental performance and identify critical factors relating to the environmental performance of the existing waste management system in Phuket. Life cycle assessment (LCA) is employed as the evaluation tool.

LCA is a technique for assessing the environmental aspects and potential impacts associated with a product (or service), by compiling an inventory of relevant inputs and outputs of the product system; evaluating the potential environmental impacts associated with those inputs and outputs; and interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study [1].

LCA considers the entire life cycle of products or services – from cradle to grave (from raw material acquisition through production, use and disposal). It is thus a holistic assessment methodology of products or services. LCA has been proven to be a valuable tool to document the environmental considerations that need to be part of decision making towards environmental sustainability [2,3].

LCA has been successfully utilized in the field of solid waste management, for example, to assess differences in environmental performance between different waste incineration strategies [4] or related activities such as flue gas cleaning process of MSW incinerators [5], to compare the environmental performance of different scenarios for management of mixed solid waste as well as of specific waste fractions [6-12]. It has also been successfully utilized for comparative assessment of MSW systems in the Southeast Asian region [13-17].

2. METHODOLOGY

Environmental impacts of the existing waste management system in Phuket are evaluated in a life cycle perspective. LCA is used as the evaluation tool. In the following sections each phase of LCA adopted in this study is explained.

2.1 Goal and scope definition

The goal of this study is to evaluate the environmental performance and identify critical factors relating to the environmental performance of the existing waste management system in Phuket. The composition is specified in Table 1 [18]. The functional unit (FU) providing a reference to which the inputs and outputs are related is defined as "1 ton of Phuket MSW treated".

Table 1. Phuket MSW composition.

Composition	Amount (%)
Food waste	44.13
Plastic	15.08
Paper	14.74
Glass	9.67
Yard waste	5.26
Metals	3.44
Rubber/leather	2.28
Cloth	2.07
Stone/ceramic	1.39
Other	1.94

System boundaries of this study are shown in Figure 1. Unit processes enclosed by dashed line are currently implemented in Phuket. As there are no recycling plants in Phuket, sorted materials including paper, plastic, glass, aluminium and steel are transported for recycling in other places around 750-900 km from Phuket.

The system boundaries include collection and transportation of MSW from its source to be treated by incineration, recycling and landfilling without energy recovery. Besides direct processes relating with waste management systems, other relevant processes interacting with the waste management systems are also included. Production of energy, i.e., electricity and diesel, are included as such energy is directly used in waste management systems and background systems. There is no power production for Phuket in particular. The electricity used in Phuket facilities is provided by the conventional power plants through the national grid. Information regarding the conventional power production has been provided by Electricity Generating Authority of Thailand (EGAT) [19]. Lime production is included as lime is used in air pollution control unit in the incineration plant. Capital equipment is not included in the study as it is considered that emissions from production of the equipment are very small compared to those released during the use of the equipment.

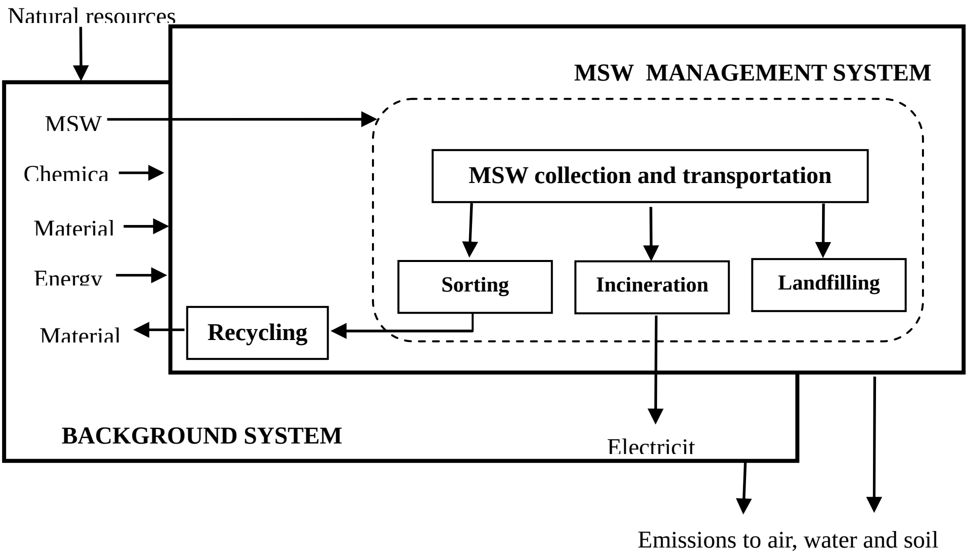

Figure 1. System boundaries of the study.

The system expansion approach is used for the evaluation in cases where useful products are produced from the waste treatment system and displace the products produced from virgin resources by other systems. In this study, this approach is valid in the evaluation of electricity recovered from incineration and recycled products from recycling processes. These waste treatment systems, namely incineration and recycling, are expanded to include the alternative processes producing an equivalent amount of the recovered products and are credited from avoiding the production by those alternative processes. This is based on the assumption that the properties of the recovered product and the product from virgin resources are identical.

Environmental impact categories were set to reflect the environmental effects that are relevant to the waste management. The impact categories include global warming (GW), photochemical ozone formation (PO), acidification (AC) and nutrient enrichment (NE). It is important to note that not all relevant environmental impacts are included in this study due to their insignificance and unavailability of relevant data. For example, ozone depletion is ignored as the considered systems result in insignificant amount of ozone depleting gases. Dioxins in fly ash as well as toxic substances in leachate and in flue gas which pose significant toxicity are excluded in the study due to lack of relevant data.

The LCA result will support Phuket Municipality for further planning and optimizing improvements or strategies of MSW management.

2.2 Inventory approach

This phase has been done for compiling all inputs and outputs of resources, raw materials, energy and environmental emissions in the system boundaries illustrated in Fig.1.

Emission factors of MSW collection and transportation were obtained from the Automotive Emission Laboratory following methodology of the Thai Industrial Standards

Institute - TISI 1290-1995 and TISI 1295-1998. Energy consumption and emissions in Phuket MSW management system were mostly obtained from the actual processes at the study site. Fossil carbon dioxide emitted from incineration system was calculated by using carbon dioxide emission factors [20]. Methane gas from landfill was calculated by multiplying waste fractions with the corresponding emission factors obtained from literature [21]. Emissions from exhaust of diesel engine used for spreading and compaction in landfill were calculated by using emission factors [22]. Information of material recycling obtained from literature and database are as follows: paperboard [23], office paper and newsprint [24], plastic [25,26], glass and steel [27], aluminium [28].

Some key references for other relevant data are: lime production [29], diesel production [30]. Emission factors from the combined conventional electricity production in Thailand of 2001 (76.42% natural gas, 23.56% coal and 0.02% oil) [31] were used for computing the credits from electricity recovered during waste treatment.

2.3 Impact assessment methodology

Potential environmental impacts were calculated based on the data from the inventory analysis. For impact assessment, the inventory data are classified into the environmental impact categories according to effects they contribute and then characterized. The equivalency factors for GW (over a time horizon of 100 years) are obtained from the Intergovernmental Panel on Climate Change (IPCC) 2001 [32] and the Environmental Design of Industrial Products (EDIP) [33]. According to IPCC, the GWP of CO varies between 1 and 3, hence the EDIP value of 2 is considered. Those of PO for low NO_x areas are from [34], AC and NE are from [35].

2.4 Interpretation

Finally, useful results from inventory analysis and impact assessment are discussed in accordance with the goal and scope of the study.

3. RESULTS AND DISCUSSION

3.1 Results from impact assessment

After compiling all inputs and outputs of resources, raw materials, energy and environmental emissions in the system boundaries, the result shows the contribution to environmental impact potentials of each unit processes. In this study environmental impact potentials focused on are global warming, photochemical ozone formation, acidification and nutrient enrichment.

The environmental impact potentials per 1 ton of Phuket MSW treated of each unit processes in the existing waste management system in Phuket are presented in Table 2.

Table 2. Environmental impact potentials of each unit processes in the existing waste management system in Phuket.

Unit process	Environmental impact potential (per 1 ton of Phuket MSW treated)			
	Global warming (kg CO_2 eq.)	**Photochemical ozone formation** (kg C_2H_4 eq.)	**Acidification** (kg SO_2 eq.)	**Nutrient enrichment** (kg NO_3^- eq.)
MSW transportation	2.63E-2	5.26E-4	4.25E-2	8.19E-2
Incineration	4.17E+2	1.65E-2	1.35E+0	2.06E+0
Landfilling (without energy recovery)	6.28E+2	1.92E-1	6.18E-3	1.11E-2
Paperboard recycling	-8.61E-1	7.53E-4	-2.20E-3	7.09E-3
Office paper recycling	3.28E-1	1.06E-3	5.19E-3	9.30E-3
Newsprint recycling	-6.50E-1	2.56E-3	8.12E-3	1.61E-2
PVC recycling	8.32E-1	-4.88E-5	-9.33E-4	-1.00E-2
PS recycling	-3.46E-1	-2.59E-4	-1.68E-3	-8.72E-3
PE recycling	1.39E+0	-4.67E-4	4.61E-3	-3.21E-3
PET recycling	-1.16E-1	-9.66E-5	-2.51E-3	-4.21E-3
PP recycling	-6.08E+0	-1.16E-3	-1.91E-2	-2.81E-2
Glass recycling	-6.35E+0	2.12E-3	-3.71E-2	-2.25E+0
Aluminium recycling	-1.77E+1	4.76E-4	-4.21E-2	-4.39E-3
Steel recycling	-9.22E+0	-6.89E-3	-2.10E-2	-1.63E-2
Net environmental impact potential	**1.01E+3**	**2.07E-1**	**1.29E+0**	**-1.39E-1**

Each environmental impact potential of the existing waste management system in Phuket is described below:

3.1.1 Global warming

Result from impact assessment shows that the net global warming potential is 1,006 kg CO_2 equivalent. In addition, it shows that major processes contributing to global warming are incineration and landfilling.

From background analysis of the incineration, high amount of fossil CO_2 is generated during MSW combustion and contributes at the amount of 474 kg CO_2 equivalent. Due to electricity production at the incinerator, the environmental burdens from a conventional power plant are avoided. The avoided environmental impact potential is presented in the negative values and is -70 kg CO_2 equivalent for global warming potential. The combustion process including the relevant processes and the avoidance from electricity production are accounted to the net global warming potential from incineration of 417 kg CO_2 equivalent.

Landfill has the most contribution to global warming potential. The potential directly comes from the emission of CH_4 from MSW degradation. Since there is no gas collection and flaring system and with the assumption of 10% methane oxidation in landfill cover, 90% of the methane produced is released to the atmosphere. Landfilling contributes 628 kg CO_2 equivalent or approximately 62% of the net contribution.

Many unit processes in the waste management system have the negative potential of global warming. This means that products from these unit processes can replace products manufactured from virgin resources, thus, impacts from the virgin manufacturing can be avoided. In aluminium recycling, for example, recycled aluminium ingot can replace aluminium ingot from bauxite ore. Therefore, impacts from processes relating with aluminium ingot production, i.e. bauxite mining, alumina production, anode production, electrolysis, ingot casting and transportation can be avoided.

3.1.2 Photochemical ozone formation

The net photochemical ozone formation potential is of 0.21 kg C_2H_4 equivalent. MSW degradation in landfill has the most contribution to this impact potential. Methane gas emitted from the MSW degradation contributes at the amount of 0.19 kg C_2H_4 equivalent or approximately 92% of the net contribution. In other unit processes, major contributors to this impact are CO and VOCs.

Like global warming, many processes in the waste management system have the negative potential of the photochemical ozone formation. This means that products from these unit processes can replace products manufacturing from virgin resources, thus, impacts from the virgin manufacturing can be avoided. However, this avoidance is too little to overcome the effect from other processes.

3.1.3 Acidification

It can be seen in Table 2 that the acidification potential is 1.29 kg SO_2 equivalent. This impact potential is mainly contributed from MSW combustion in incineration (1.49 kg SO_2 equivalent). However, the magnitude of contribution from this activity is not much because some sulfur dioxide and hydrogen chloride are removed by the air pollution control unit. Details of the evaluation reveal that nitrogen dioxide is a critical factor for the acidification since de-NO_x equipment has not been installed in the incineration plant. In other unit processes, major contributors to this impact are SO_2 and NO_2.

Many processes have the negative potential of acidification as explained for global warming and photochemical ozone formation. However, the avoidance cannot overcome the acidification effect from other processes resulting in a positive magnitude of the acidification potential.

3.1.4 Nutrient enrichment

The highest potential to nutrient enrichment is contributed by nitrogen dioxide in the combustion process at 2.13 kg NO_3^- equivalent. The level of the nutrient enrichment effect is reduced by impact avoidance from many processes, especially glass recycling, consequently the net impact potential is of -0.14 kg NO_3^- equivalent.

In glass recycling, for example, recycled glass can replace glass from virgin resources. Therefore, impacts from manufacturing of glass from virgin resources can be avoided. Details of the evaluation reveal that nitrogen and phosphate, as water emissions from virgin glass manufacturing, are critical factors for the nutrient enrichment. Avoidance of these major emissions by recycling results in a reduction of the nutrient enrichment potential.

3.2 Interpretation

Besides the results in section 3.1 it is often interesting to analyze the results in more detailed way. In this section, the significance of comparative waste management systems-incineration, landfilling and recycling are analyzed. Some aspects which may influence the environmental performance of the existing waste management system in Phuket are reported.

3.2.1 Significance of comparative waste management systems

Based on 1 ton of waste treated by incineration, landfilling and recycling, the impact potentials contributed from the three waste management systems are presented in Table 3.

Table 3. Impact potential comparison of waste management systems.

Waste management system	**Environmental impact potential (per 1 ton of waste treated by each system)**			
	Global warming (kg CO_2 eq.)	**Photochemical ozone formation** (kg C_2H_4 eq.)	**Acidification** (kg SO_2 eq.)	**Nutrient enrichment** (kg NO_3^- eq.)
Incineration	5.84E+2	2.31E-2	1.89E+0	2.88E+0
Landfilling	2.46E+3	7.52E-1	2.42E-3	4.33E-3
Recycling	-1.24E+3	-6.23E-2	-3.47E+0	-7.32E+1

From Table 3, it can be concluded that among all comparative systems incineration is the significant system contributing the highest potentials to acidification and nutrient enrichment. Landfilling contributes to the highest potentials to global warming and photochemical ozone formation. Considering recycling system, the total impact from recycling system is less than the total impact from manufacturing of products from virgin materials resulting in negative value of the net potential impacts. Thus, in the existing waste management system, recycling plays the best role in environmental effectiveness beneath the study scope. Therefore, source separation for material recycling should be promoted.

3.2.2 Effect of plastic waste combustion

Result from the inventory analysis indicates that high amount of fossil CO_2 is emitted due to combustion of plastic waste. Plastic waste is a major factor contributing to the global warming in combustion process. Closer analysis reveals that one kilogram of plastic waste contributes to a global warming potential of approximately 2.66 kg CO_2 equivalent. The high potential of global warming could be reduced by increasing the efficiency of plastic separation.

The energy recovered from waste incineration, however, would be decreased because a large fraction with high energy content is separated out. Thus the strategy of plastic separation to be treated by either landfilling or recycling should be further assessed against the strategy of incineration including plastic fraction.

3.2.3 Effect of high moisture content of the feedstock

A closer analysis revealed that incineration requires a large amount of energy for waste combustion and the energy recovery efficiency of the existing incineration seems very low (7%). This may be due to high moisture content of the feedstock to the incinerator. The moisture content of the waste to be incinerated is as high as 41%.

If feedstock with high moisture content is sent to the incinerator, much of the gross calorific content of the waste is used up evaporating this moisture. The latent heat contained within the flue gas is not normally recovered. The amount of heat wasted per kg of water in the feedstock in the form of water vapor in the exhaust gases is 2,636 kJ/kg [36]. Therefore, separation of high moisture content waste fractions from the waste to be incinerated and improvement of the operation efficiency of the incineration plant must be considered to improve the environmental performance of MSW incineration.

3.2.4 Effect of nitrogen dioxide

Details of the evaluation reveal that NO_2 from waste combustion is a major contributor to acidification and nutrient enrichment. Nitrogen dioxide emissions might be reduced by installation of various types of de-NO_x processes, typically either SCR (Selective Catalytic Reduction) or SNCR (Selective Non-Catalytic Reduction). In both the processes, ammonia (NH_3) in some form is injected into the flue gas stream where it reacts with the NO_x to form nitrogen (N_2) and water. SCR works with a catalyst at lower temperatures (175-500°C) than SNCR (850-950°C) which works without a catalyst. Information from Spectra Gases Inc. (USA) has indicated that by using SCR, the reduction percentages to be obtained (>90%) are generally higher than with SNCR (<70%).

From the incineration analysis, NO_2 from combustion process contributes 1.10 kg SO_2 equivalent and 2.13 kg NO_3^- equivalent per 1 ton of Phuket MSW treated. If 70% of NO_2 from waste combustion is removed by de-NO_x equipment, the net potentials of acidification and nutrient enrichment per 1 ton of Phuket MSW treated will be 0.52 kg SO_2 equivalent (decreased 60%) and -2.08 kg NO_3^- equivalent, respectively.

3.2.5 Effect of landfill gas recovery

The emission of greenhouse gas from landfilling, which is predominated by methane, could be reduced by introduction of gas collection and flaring system to convert the methane gas to carbon dioxide which, being of biomass origin, will not contribute to global warming. Additional credits can be obtained if the collected methane is utilized as an energy source.

For the purpose of estimation, it is assumed that energy recovery is related to methane gas alone. The heating value of methane is typically 50-55 MJ/kg and has been set at 50 MJ/kg in this analysis. It is assumed that 50% of methane gas produced is collected to produce electricity by an engine with 35% efficiency and 10% of uncollected portion is oxidized in landfill cover. Therefore, 45% of the methane gas is emitted to the atmosphere. From analysis, 50% recovery of landfill gas leads to the reduction of 36% GWP, 35% POP, 13% AP and 0.24 kg NO_3^- equivalent per 1 ton of Phuket MSW treated.

4. CONCLUSION

The net potentials of global warming, photochemical ozone formation, acidification and nutrient enrichment of the existing waste management system are 1,006 kg CO_2 equivalent, 0.21 kg C_2H_4 equivalent, 1.29 kg SO_2 equivalent and -0.14 kg NO_3^- equivalent, per ton of Phuket MSW treated, respectively. Landfilling contributes the highest potentials to global warming and photochemical ozone formation due to methane emitted from waste degradation. Besides landfilling, incineration plays a major role in contributing to the global warming potential due to the emission of fossil carbon dioxide from plastic burning. Nitrogen dioxide from combustion process is a critical factor contributing to acidification and nutrient enrichment. The study suggests the separation of plastic fractions and wet feedstocks from the waste stream to be incinerated as a first priority because they are quite easy to be accomplished. Source separation for material recycling, landfill gas recovery and introduction of de-NO_x equipment should be pursued.

5. ACKNOWLEDGMENTS

This work was financially supported by the Joint Graduate School of Energy and Environment (JGSEE), King Mongkut's University of Technology Thonburi. The authors gratefully acknowledge the Phuket Municipality and Kumjornkit Construction Company Limited for providing data. The authors also acknowledge the contribution of Dr. Sirintornthep Towprayoon and Dr. Chart Chiemchaisri during the research.

6. REFERENCES

[1] ISO (1997) *Environmental standard ISO 14040*. Environmental management – Life cycle assessment – Principles and framework, Reference Number: ISO 14040: 1997(E).

[2] Gheewala, S.H. (2003) Application of Life Cycle Assessment to Cleaner Production, *International Energy Journal*, **4**(1), pp. 5-15.

[3] UNEP. (2003) *Environmental management tools: life cycle assessment*. http://www.uneptie.org/pc/pc/tools/lca.htm.

[4] Bergsdal, H., Strømman, A. H. and Hertwich, E.G. (2005) Environmental Assessment of Two Waste Incineration Strategies for Central Norway, *International Journal of Life Cycle Assessment*, **10**(4), pp. 263-272.

[5] Chevalier, P., Rousseaux, P., Benoit, V. and Benadda, B. (2003) Environmental assessment of flue gas cleaning processes of municipal solid waste incinerators by means of the life cycle assessment approach, *Chemical Engineering Science*, **58**, pp. 2053-2064.

[6] Mendes, R.M., Aramaki, T. and Hanaki, K. (2004) Comparison of the environmental impact of incineration and landfilling in São Paulo City as determined by LCA, *Resources, Conservation and Recycling*, **41**, pp. 47-63.

[7] Arena, U., Mastellone, M.L. and Perugini, F. (2003) The environmental performance of alternative solid waste management options: a life cycle assessment study, *Chemical Engineering Journal*, **96**, pp. 207-222.

[8] Ross, S. and Evans, D. (2003) The environmental effect of reusing and recycling a plastic-based packaging system, *Journal of Cleaner Production*, **11**, pp. 561-571.

[9] Finnveden, G., Johansson, J., Lind, P. and Moberg, Å. (2000) *Life cycle assessments of energy from solid waste*. fms 137. FOA-B-00-00622-222-SE, Stockholms universitet, Sweden.

[10] Sonesson, U., Björklund, A., Carlsson, M. and Dalemo, M. (2000) Environmental and economic analysis of management systems for biodegradable waste, *Resources, Conservation and Recycling*, **28**, pp. 29-53.

[11] Finnveden, G. and Ekvall, T. (1998) Life cycle assessment as a decision-support tool – the case of recycling vs. incineration of paper, *Resources, Conservation and Recycling*, **24**, pp. 235-256.

[12] Denison, R. (1996) Environmental life-cycle comparisons of recycling, landfilling, and incineration: A review of recent studies, *Annuual Review of Energy and the Environment*, **21**, pp. 191-237.

[13] Chaya, W. and Gheewala, S.H. (2006) Life cycle assessment of MSW-to-energy schemes in Thailand, *Journal of Cleaner Production* (in press).

[14] Wanichpongpan, W. and Gheewala, S.H. (2006) Life cycle assessment as a Decision Support Tool for Landfill Gas-to Energy Projects, *Journal of Cleaner Production*

(in press).

[15] Aye, L. and Widjaya, E.R. (2005) Environmental and economic analyses of waste disposal options for traditional markets in Indonesia. *Waste Management*, (in press)

[16] Liamsanguan, C. and Gheewala, S.H. (2004) Environmental Evaluation of Municipal Solid Waste Management in Phuket: A Life Cycle Perspective. *Proceedings of the Joint International Conference on Sustainable Energy and Environment (SEE), 1-3 December 2004, Hua Hin, Thailand*, pp. 619-623.

[17] Tahara, K., Inaba, A., Sakane, Y. and Kojima, T. (2002) A Case Study of the Garbage Treament Technology. *SETAC 10th LCA Case Studies Symposium, Barcelona, Spain*, pp. 141-144.

[18] PCD (2003) *Domestic waste utilization and minimization from municipalities_ content and volume*. The Pollution Control Department. http://www.pcd.go.th/info_serv/en_waste_municip.html.

[19] EGAT (Electricity Generating Authority of Thailand). http://www.egat.co.th.

[20] Sundqvist, J.-O., Finneveden, G., Albertssun, A.-C., Karlsson, S., Berendson, J. and Höglund, L.O. (1997) *Life Cycle Assessment and Solid Waste- Stage 2*, AFR-Report 173, AFR, Swedish Waste Research Council.

[21] Sandgren, J., Heie, A. and Sverud, T. (1996) Utslipp ved håndtering av kommuanalt avfall. Statens forurensningstilsyn (SFT). TA-number 1336/1996 in Friðriksson, G.B., Johnsen, T., Bjarnasóttir, H.J. and Slentnes, H. (2002) *Guidelines for the use of LCA in the waste management sector*. Nordtest Project nr. 1537-01.

[22] Riso Narional Laboratory, Ministry of Science, Technology and Innovation, Denmark. *Emission factors for fuel*

combustion.
http://www.risoe.dk/sys/esy/emiss_e/inventories.htm.

[23] Ongmongkolkul, A. and Nielsen, P.H. (2002) *Life Cycle Assessment of Paperboard Packaging Produced in Thailand*.
http://www.howproductsimpact.net/box/.

[24] Byström, S. and Lönnstedt, L. (1997) Paper recycling: environmental and economic impact. *Resources, Conservation and Recycling*, **21**, pp. 109-127.

[25] CE. (1994) *Centrum voor Energiebesparing en schone technologie: Verwijdering van huishoudelijk kunststofafval, analyse van milieu-effecten enkosten*, Delft, The Netherlands, 15 september 1994 (Bijlagen, page 69).

[26] PlasticsEurope (2005) *Eco-profiles of the European Plastics Industry*. Association of Plastics Manufactures. http://www.plasticseurope.org.

[27] BUWAL 250 (1996) *Ökoinventare für Verpackungen, Schriftenreihe Umwelt 250*, Bern.

[28] International Aluminium Institute (2003) *Life Cycle Assessment of Aluminium: Inventory Data for the Worldwide Primary Aluminium Industry*.

[29] ETH-ESU (1996) *Öko-inventare von Energiesystemen*, FRISCHKNECHT *et al*. (1996), 3rd edition.

[30] BUWAL 300. Dall'Acqua, S. (1997) *Separation into precombustion and combustion for the different thermal energy carriers of BUWAL 250*, EMPA St. Gallen, September 1997 (internal report, unpublished results).

[31] TEI (2003) *Final report for the project on life cycle assessment for Asian countries-Phase III*. Thailand Environment Institute, Thailand.

[32] IPCC (2001) *Third Assessment Report: Climate Change*.

Intergovernmental Panel on Climate Change.

[33] Wenzel, H., Hauschild, M. and Alting, L. (1997) *Environmental Assessment of Products, Vol. 1: Methodology, tools and case studies in product development*. Kluwer Academic Publishers.

[34] Andersson-Sköld, Y., Grennfelt, P. and Pleijel, K. (1992) Photochemical ozone creation potentials: a study of different concepts. *Journal of Air and Waste Management*, E, **42**(9), pp. 1152-1158 in Hauschild, M. and Wenzel, H. (1998) *Environmental Assessment of Products Volume 2: Scientific background*. Chapman & Hall, UK.

[35] Hauschild, M. and Wenzel, H. (1998) *Environmental Assessment of Products Volume 2: Scientific background*. Chapman & Hall, UK.

[36] Thompson, S. (2002) Integrated Management of Solid Wastes for New York City. *American Society of Mechanical Engineers Proceedings of NAWTEC, 10 May 2002*, pp. 69-86.