早稲田大学大学院環境・エネルギー研究科

博士学位論文

Analysis and proposals for the development of sustainable municipal solid waste management methods in developing Asian countries

アジア新興国におけるサステナブルな都市廃棄物の処理・管理手法の開発に関する分析と提案

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1. 1 Introduction

1.1.1 Background of the study

Municipal Solid Waste (MSW) in the developing Asian countries is changing rapidly in its composition and volume along with the growth of population, urbanization, industrialization, and economic development. These growths come with increased of waste production. They may lead to severe environmental damage to the air, water, and soil if not accompanied with a sustainable waste management. Developing countries in Asia have similarity in terms of its waste composition and characteristics. High moisture due to the high percentage of organic waste results in low calorific value and in methane gas potential. This particular characteristic makes them less suitable for thermal treatments and more suitable for biological treatment such as composting and anaerobic digestion. The organic waste, when dumped in landfills will not only pollute the air by releasing green house gases such as the methane and carbon dioxide, but also requires an energy intensive leachate water treatment. Unfortunately, landfilling is still the main practice of waste handling and the rate of waste collection is still rather low[1]. Many landfills in Asian developing countries are not sanitary landfills. Therefore, often the leachate water contaminates the underground water that will cause diseases for the community living around the dumpsite.

Major disasters caused by improper MSWM including the one occurred in Bandung city, Indonesia in 2005 where 31 people were killed and buried under the collapsing municipal waste landfill landslides following heavy rains[2]. Improper waste incinerations also cause health problems such as the one affecting the community living near an incineration plant in Jiangsu province, China[3]. Moreover, flooding in the big cities of Asia is often caused by drainage blocked by uncollected municipal waste such as the case in Jakarta city Indonesia[4].

1.1.2 Objective of the study

To address the complex issues related to MSWM, the conduction of a comprehensive Life Cycle Assessment (LCA) study is necessary. Moreover, a Strength, Weakness, Opportunity and Threats (SWOT) analysis may help to find out how the new and more sustainable technology could adapt in the concerned location. Energy consumption and pollution should be known for the assessment. There are many uncertainties including humidity, temperature, and the different kinds of waste characteristics that are fed in to the waste treatment plant. These uncertainties are often very different from one region to another. The research objectives include, the elaboration of the current practices and the problems that come with it, identification of the previous researches that have been done and the room for improvements, and the proposal of environmentally sound strategies and its economic sustainability assessment. Three pillars of sustainability; environmental, economic, and social

[1] (IGES , 2012)
[2] (The Guardian, 2005)
[3] (The Guardian, 2012)
[4] (The Jakarta Globe, 2009)

dimensions are to be analyzed and carefully measured in this study to ensure long-term sustainability of waste management technology adaptation. By touching upon the three aspects evaluation, a holistic and sustainable solution is hoped give contribution in the development of sustainable MSWM in the developing countries in Asia.

1.2. Research method

1.2.1 Literature review of previous studies, existing LCA and economic assessment models for MSWM

For environmental assessment, the tool chosen in this study was Life Cycle Assessment (LCA). A customable model of LCA methodology, the Environmental load Point (ELP) has been utilized to integrate the social aspect in the quantification process. To assess economic feasibilities, the tool practiced in this study was Cost Benefit Analysis (CBA), which is similar to Life Cycle Cost (LCC)[5].
Some of the previous studies of LCA application on Asian MSW were done for Yogyakarta[6], Bali[7], Indonesian food markets[8], Thailand[9], and China[10]. These studies mostly used SimaPro or BUWAL softwares with European inventory data (Julian, 2009) and some derived data from the existing plant in the country. The scenarios constructed in the above mentioned studies include landfilling, AD, incineration, composting and biological mechanical treatment (BMT)[11]. Table 1.1 explains the detailed literature review of previous studies that are similar to our study. Three LCA on MSW case study were done at the same year, 2006, in three Asian countries; Indonesia, Thailand and China. The Indonesian case study was done in the University of Melbourne in Australia with focus on market waste in Indonesia. The Thailand case study was done in King Mongkut University of Technology in Thailand with focus on technology options with energy recovery. The Chinese case study conducted by Shanghai University in China focused on Material Biological Treatment (BMT) in Pudong province. The three studies were using the similar LCA methodology based on ISO 14040 and the European emission factors provided by softwares like simaPro. The use of generic inventory data from European country is common due to the inexistence of local data in that period of time. The impact categories they employed were also similar, which are global warming, acidification, eutrophication, and photochemical formation. The study from Thailand was quite more advanced than the other two because it has covered additional category impacts such as ozone depletion, resource consumption and generation of solid waste to be disposed in the landfill. Results from the three studies showed a similarity where biological waste treatment is more preferable than the other options. The Indonesian market waste case study proposed composting due to its medium environmental impact and more affordable cost. The Thai waste-to-energy case study proposed anaerobic digestion over incineration due to the high moisture and low calorific value of Thai waste

[5] (Finnveden, Bjorklund, Moberg, & Ekvall, 2007)
[6] (Gunamantha and Sarto, 2012)
[7] (Zurbrügg et al., 2012)
[8] (Aye and Widjaya, 2006)
[9] (Liamsanguan and Gheewala, 2008; Wirawat and Gheewala, 2007)
[10] (Hong et al., 2006)
[11] (Diaz and Warith, 2006)

characteristics. And the Chinese case study proposes BMT in parallel with composting.

Table 1.1 LCA case studies for municipal waste management in developing Asian countries

Site of case study	Year	Author's Institution	Methodology and Scenarios	Impact categories	Results
INDONESIA MSW in Karamantul Region, Yogyakarta,	2012	Gadjah Mada University and Ganesha University of Education	Methodology: Simplified LCA Scenarios: Landfilling without energy recover, Landfilling with energy recovery, Incineration +AD, Gasification + AD, Direct Incineration, Direct Gasification	Global warming, Acidification, Eutrophication, Photochemical oxidant formation	The best scenario is direct gasification + landfilling (in global warming, eutrophication and photochemical oxidant categories) and Gasification + AD + landfilling (in acidification category)
INDONESIA (Traditional market waste only)	2006	The University of Melbourne(Australia)	Methodology: LCA with SimaPRO with European emission factors Scenarios: Composting in labor intensive plants, Composting in centralized plants, Biogasification in centralized plants, Landfill gas capture	Greenhouse effect, Acidification, Eutrophication, Photochemical oxidant effect	The best scenario is Biogasification with energy recovery (lowest env. Impact) but Centralized composting is supported due to economic feasibility and community support
INDONESIA MSW in Gianyar, Bali	2012	Swiss Federal Institute of Aquatic Science and Technology (Switzerland)	Methodology: Analysis from Observations, Group discussion, and Interviews Scenario: Composting	Indicator: Technical Appropriateness, Health & Environment, Economic Aspects, Social Aspects, Organization and Institution	The study was not able to determine the relative importance of the indicators to contribute to the success of the composting project AHP is recommended to be done

THAILAND, MSW in Thailand	2006	King Mongkut's Institute of Technology (Thailand)	Methodology: LCA according to ISO 14040-1 as outlined in Wenzel et al. 1997 Scenarios: Incineration with electricity recovery, Anaerobic digestion with electricity recovery	Global warming, Acidification, Nutrient Enrichment, Photo-oxidant formation, Stratospheric ozone depletion, Heavy metals, Consumption of energy resources, Generation of solid waste to landfill	Anaerobic digestion is more preferred than incineration due to high biodegradable waste percentage and high waste moisture
THAILAND, MSW in Phuket	2008	King Mongkut's University of Technology (Thailand)	Methodology: Energy and GHG emission LCA Scenarios: Incineration and Landfilling	Greenhouse gas emission from direct activity and life cycle, Energy consumption	Incineration is superior to landfilling
CHINA, MSW in Pudong	2006	Shanghai University, China	Methodology: LCA Scenarios: Landfill, incineration, BMT + landfill, BMT + Incineration, BMT+compost	Global warming, Acidification, and Eutrophication	landfill = highest global warming & eutrophication potential incineration = highest acidification potential, Best is BMT+compost

Source: Compiled by author

The later LCA studies conducted by universities and research institutes evolved in line with the demand of knowledge and the development of the real practices. The real practices often involve international funding, privatization, and partnerships between the government and the private or international organization sectors. For example, the option of landfill gas (LFG) collection for energy recovery is involved in the Indonesian case study in 2012. At the same time, the Indonesian CDM projects related to MSW registered in the UNFCCC are dominated with LFG energy recovery projects. The 2008 Phuket, Thai case study also focused more on the Green House Gas (GHG) emission and proposes incineration over landfilling for better energy recovery and GHG emission reduction.

The popularity of covering more comprehensive parameters such as the social aspects, organizational and institutional issues, economic aspects, and technical appropriateness was apparent in the newer studies. Swiss Federal Institute of Aquatic Science and Technology cover all these parameter in their study of Gianyar Bali in 2012. This trend might be the result of unsustainability of projects which decision making only relied purely from the traditional LCA that only involves environmental aspects. The Bali study emphasizes the need of community group discussions and interviews to reach the rather abstract parameters that could be the key of project

sustainability. The recommended methodology by the Bali study was Analytic Hierarchical Process (AHP) questionnaire. Our study used this approach to weight the result of our LCA study.
In its early development, Life Cycle Assessment (LCA) was intended to assess product manufacturing. LCA framework, data quality standards and impact assessments were developed in 1989 to 1992 at the SETAC's code of practice workshop I to IV in Vermont, Leiden, Virginia and Florida[12]. One of the earliest studies on the application of LCA to Municipal Solid Waste (MSW) was conducted in 1999 at the Stockholm University in Sweden. They determined the system boundaries and Life Cycle Impact Assessment (LCIA) methodological aspects of life cycle assessment of integrated solid waste management. One of the earliest and widely used guidelines for LCA application was prepared by Nordtest organization from Finland in 2002. Although the focus was for Nordic countries, the guideline is modifiable for application in other countries. This guideline contains the boundaries and general assumptions that may be made in conduction LCA for Municipal Solid Waste Management (MSWM) for different technologies, namely, incineration, aerobic composting, anaerobic digestion, landfills, biocells, and how to address the substituted energy and mineral compost fertilizer.
In 2006, a study from Ryerson University, Canada compared different LCA models for waste management. This study elaborate and proposed an LCA model called WASTED (Waste Analysis Software Tool for Environmental Decisions). This model is a Microsoft excel based model with the basis of Material Flow Assessment (MFA) approach[13]. In 2007, Swedish Environmental Research Institute from Sweden analyzed the mechanism to incorporate indirect impacts into LCA quantification and also discussed the applicability of LCA results for policy making. The main finding of this study is the need of including economic data in addition to the technological and environmental data to make it a more comprehensive tool of assessment for decision-making.
In addition to popularly used software of LCA such as SimaPro, GaBi and GEMIS, there are other models that are specifically used for waste management such as IWM 2, ARES, EA SEWASTE, WASTED, ORWARE, EPIC / CSR, DST, and Umberto[14]. Comparative study has shown that the existing models are useful for environmental engineers, waste managers, and decision makers for determining the environmental implications of solid waste management. However they cannot provide the inclusion of geographic, social and political factors[15]. Other comparative studies of the existing models[16], argue that the models are most suitable only in the country they were designed, for example EA SEWASTE in Denmark, EPIC ICSR in Canada, IWM 2 in UK, ORWARE in Sweden. Table 1.2 lists the existing methodologies used for municipal waste management LCA.
This study distinguishes itself from other studies in the sense that it proposes an LCA model called ELP (Environmental Load Point) formulated in Japan (Waseda University, Nagata Laboratory, Tokyo) that allows higher flexibility of adjustability to the local social, political and other sustainability factors, and higher transparency of data and calculation, which often is lacking in the commercially sold models[17].

[12] (Shahorly et. al., 2008)
[13] (Diaz et al., 2006)
[14] (Jörg and Bilitewski, 2007; Gentil et al., 2010)
[15] (Diaz and Warith, 2006)
[16] (Gentil et al., 2010)
[17] (Diaz and Warith, 2006)

Table 1.2 Existing Life Cycle Assessment models for waste management

Model	Developer	Software	Number of substances modelled
ELP	Waseda University, Nagata laboratory	EXCEL	Total: 186
IWM 2	Procter & Gamble corp. (UK)	SQL Database	Air: 24 Water: 27
ARES	ARES Energiesysteme GmbH (GERMANY)	EXCEL	Air: 121 Water: 153
ORWARE	Swedish University of Agricultural Sciences and other institutions* (SWEDEN)	Matlab/Simulink	Air: 69 Water: 68
EPIC / CSR	Environment and Plastics Industry Council EPIC (CANADA)	EXCEL	Air: 12 Water: 5
DST	University of North Carolina (USA)	EXCEL / CPLEX	Air: 23 Water: 17
UMBERTO	Institute fuer Umweltinformatik Hamburg GmbH (GERMANY)	Borland Database Engine	Not limited

Source: Jorge Winkler, 2007. *Other institutions: * Swedish Institute of Agricultural and Environmental Engineering, Royal Institute of Technology, Kungliga Tekniska Högskolan, Swedish Environmental Research Institute

1.2.2 World Analysis of MSWM technologies and practices

Advanced technologies and management strategies adaptation for better municipal waste management in the developing countries is often a challenging task to do, especially because there are many factors of uncertainties. These uncertainties may be the result of lack of understanding of the business as usual, values, habits and regulations in the region. It may also be due to different climate that affects varieties in temperature, humidity, waste characteristics, energy security, and the required human resources capacity. This study elaborated and analyzed the municipal waste trend and characteristics, regulatory frameworks, and analysis of the technologies that are in practice in the region in a form of Strength, Weakness, Opportunity and Threat (SWOT) analyses for both the developing Asian countries and the developed European countries and Japan as comparison.

1.2.3 Comparative analysis of LCA methodologies

There are many available LCA methodologies in the market. Some are based on excel workbooks and the other are software based. Some methodologies only provide the LCA step, while some other is complete with the Life Cycle Impact Assessment (LCIA) steps. Some of them put importance in the problem of waste disposal, some other neglect it completely. For the purpose of selecting the appropriate methodology, this study compares several of the available methodologies. The compared methodologies in this study are ELP, Eco Points and Eco Indicator 99.

1.2.4 Application of ELP in the developing Asian countries municipal solid waste management scenarios

Natural resource scarcity and the effects of environmental destruction have pushed societies to use and reuse resources more efficiently. Waste should no longer be seen as a burden but rather as another source of material including energy fuel. This study analyses the material and energy recovery potential of three scenarios combining four waste management technologies; incineration with energy recovery, composting, anaerobic digestion and sanitary landfill gas collection as ways to recover energy and material from municipal solid waste in the three selected countries. The study utilized the ELP method with the selected approach for application in the MSWM situation of India, Indonesia and China as case studies. For better applicability, this LCA study was followed by a discussion around the real practice and the national policy related to the proposed technology.

1.2.5 Economic assessment on the proposed solution

A Cost Benefit Analysis (CBA) was conducted to follow up and support the Life Cycle Assessment (LCA) result. In other words, instead of conducting CBA in parallel with the LCA, CBA was applied to one selection of technology from the LCA study. In this way, ecological aspect has a higher priority over the economic aspect. Moreover, by this approach, an immediate and realistic solution to improve the current waste management practices may be conducted.

CBA has been commonly used for decision-making in projects, product and service assessments[18]. Life Cycle Costing (LCC) and CBA are quite similar in the methodology and model approaches. The inventory data involved are mainly the investment cost and the operational cost. Some framework studies recommend the inclusion of environmental cost even when the authorities are not yet concern about the environmental cost[19]. There are several ways to monetize environmental cost. One way is by for calculating the health damages caused or avoided by the implementation of a project. Another other way is by the monetizing the pollution costs, the land change or the job opportunity made or eliminated due to the project implementation.

Table 1.4 elaborates the frameworks and guidelines prepared by universities and research institutes to conduct Life Cycle Costing. Graz University of Technology in Austria recommends the A Zero emission Agro-based Industrial Ecosystem AIEZES model to address the costing aspect of waste management options in Southeast Asian countries. This model mainly uses CBA approach employing the investment cost of machinery used and the annual cost from the operation and maintenance. The other framework was constructed by a study in University of California in 2004. This study constructed a LCC model for for furnaces and boilers, which is applicable for waste management as well. This study recommends including installation cost of the machineries and the Net Present Value (NPV) of the operating cost.

[18] (Finnveden, Bjorklund, Moberg, & Ekvall, 2007)
[19] (Menikpura, Gheewala, & Bonnet, 2012)

Reich from Swedish Environmental Institute did another study that employs NPV approach for LCC in 2005. Reich's study is one of the earliest studies of LCA together with LCC for waste management; therefore it is often referred in the more recent studies of this field. Reich argued that using an LCC in combination with an LCA would provide difficulties due to the two different scientific disciplines and objects of analysis. For example, the functional unit in LCA is often in mass unit such as in tonne or in Kg while in the LCC it is on currency unit such as United States Dollars (USD), Euro (EUR), or Japanese Yen (JPY). The other problem that could arise is the allocation of cost. For example, the investment cost should be allocated overtime depending on the depreciation period. There are also other financial parameters included such as interest rate for any loaned costs and discounting rate to get the present value. On the other hand, in MSWM LCA, the allocation of emission could also differ over time. For example, the release of CH_4 gas from the landfill only starts significantly on the second year. Also in composting, the amount of nitrogen released to soil from mineral fertilizer is 80% in the first year while it is only 10% for composting fertilizer and the rest are released on the following years. All of these unit and allocation complications should be broken down carefully and a way to integrate them could be very challenging.

Table 1.3 Frameworks and guidelines for CBA/LCC application in waste management

Publication title	Year	Author, Institution, location	LCC model used	Recommended inventory data
Sustainable solutions for solid waste management in Southeast Asian countries[20]	2009	Uyen Nguyen Ngoc and Hans Schnitzer, Institute for Process Engineering (IPE), Graz University of Technology, AUSTRIA	Cost Benefit Analysis (CBA) approach included in the (A Zero emission Agro-based Industrial Ecosystem) AIZES methodology	Investment cost per unit machinery used and the annual cost from operation
Life-Cycle Cost Analysis of Energy Efficiency Design Options for Residential Furnaces and Boilers[21]	2004	James Lutz, et. al., University of California, UNITED STATES	LCC = installation cost + $\sum_{n=1}^{lifetime} \frac{\text{operating cost}}{(1+\text{discount rate})^n}$ $\text{Payback}_{option} = \frac{\text{EquipCost(option)} - \text{EquipCost(ba}}{\text{OprCost(base)} - \text{OprCost(option}}$	Investment cost (including installation cost) for equipment and the operating cost over the equipment lifetime (including the finance cost: discount rate, energy cost, and maintenance cost)
Economic assessment of municipal waste management systems – case studies using a	2005	Marcus Carlsson Reich, Swedish Environmental Research	Net Present Value (NPV)	The present value of all monetary costs of the studied system, including: investment costs, operative costs, decommissioning

[20] (Ngoc & Schnitzer, 2009)
[21] (Lutz, Lekov, Camilla, Chan, Meyers, & McMahon, 2004)

combination of life cycle assessment (LCA) and life cycle costing (LCC)[22]		Institute, SWEDEN		costs, and sales revenues; all discounted to present value
Nordic guideline for cost-benefit analysis in waste management[23]	2007	Scovgaard et al. Nordic Council of Ministers	NPV	Investment, Operational costs including labor, natural resources, and import of goods. Also environmental effects and health effects
Environmental and economic assessment methods for waste management decision-support; possibilities and limitations[24]	2007	Goran Finnveden et.al., Environmental Strategies Research, Stockholm, SWEDEN	Cost Benefit Analysis (CBA) Cost Effectiveness Analysis (CEA) Life Cycle Costing (LCC)	CBA: All cost and benefits, including environmental costs should be included and monetized. CEA: focus on efficient way to achieve goals LCC: including external costs such as environmental pollution. LCC can be similar to CBA
Cost for Municipal Waste Management in the EU, Final Report to Directorate General Environment, European Commission	2002	Dominic Hogg et. al., Eunomia research & consulting	CBA	Cost for collection and treatment, land acquisition, plant utilization rate, treatment of flue as, engineering, collection of methane gas, conditions for utilization of digestate and liquor from Anaerobic digestion, choice of technology, daily costs, revenues of sales, treatment and disposal of residues, recovery of energy and material, after care, price support of energy production

Source: Compiled by author

A comprehensive inventory guideline for MSW was prepared for the European Commission in 2002, titled, *Cost for Municipal Waste Management in the EU*. This guideline comprehensively lists the entire possible inventory data that should be included in the MSW CBA for different technologies namely incineration plant, landfill, compost plant, and anaerobic digestion. This guideline is later summarized and further elaborated in the *Nordic guideline for cost-benefit analysis in waste management*.

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[22] (Reich, 2005)
[23] (Skovgaard, Ibenholt, & T, 2007)
[24] (Finnveden, Bjorklund, Moberg, & Ekvall, 2007)

Life Cycle Costing done in the developing Asian countries were done in Indonesia and Thailand using slightly different approach. The Indonesian case study was done in 2006. It employed the traditional NPV formula that involves the present value of investment cost, price coefficient, operation and maintenance cost discounted throughout the project lifetime. The one done in Thailand was conducted in 2012 and it has added the sophistication of including willingness to pay to the mitigation of pollution and health damage avoidance. Table 1.4 complies the information of these two case studies.

Table 1.4 Previous LCC case studies in developing Asian countries

Publication title	Year	Author, Institution, location	LCC model used	Recommended inventory data
Environmental and economic analyses of waste disposal options for traditional markets in Indonesia[25]	2006	Lu Aye, E.R. Widjaya, University of Melbourne, AUSTRALIA	NPV_{cost} = (I x SP) + OM $(\frac{1-(1+i)^t}{i})$ $NPV_{revenue}$ = (R_p + R_{ghg}) + $(\frac{1-(1+i)^t}{i})$ $NPV_{benefit}$= $NPV_{revenue}$ - NPV_{cost}	I: Investment cost, SP: Shadow price coefficient, OM: Operation and maintenance cost, i: discount rate, t: project lifetime
Framework for life cycle sustainability assessment of municipal solid waste management systems with an application to a case study in Thailand[26]	2012	SNM Menikpura et. al., King Mongkut University of Technology, THAILAND	LCC_{gross} = CE + OMC + EC EC = $\sum(\mathbf{WTP_i}$ x $\mathbf{Q_i})$ LCC_{net}=LCC_{gross}-LCR LCR = Revenues from selling by-products + tipping fee + credited EC	CE: Capital expenditure, OMC: Operational and maintenance cost, EC* Environmental cost, LCR: Life Cycle Revenue, WTPi: willingness to pay for the mitigation of emissions of i^{th}substance or avoiding health damages caused by i^{th} substance, Qi: magnitude of substance i

Source: compiled by author

The two approaches differ in the scope and boundary of inventory data involved in the calculation as well as the involvement of finance parameters (discounting and interest rate). The CBA that has been conducted in this study only offers one technology chosen from LCA. The scenarios offered in the CBA in this study only differ in scale of project, therefore the environmental damage including the health damage avoided is considered to have linear correlation. Due to the assumed linear correlation, environmental cost is excluded from the CBA study.

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[25] (Aye & Widjaya, 2006)
[26] (Menikpura, Gheewala, & Bonnet, 2012)

1.2.6 Comparative analysis of the weighting approaches

Weighting, is one important step of the life cycle impact assessment. It reflects the views and values of the concerned stakeholders. Weighting also shows the priority order of the project at hand. This study presents and compares two different weighting approaches. These are, Analytic Hierarchical Process (AHP) and text mining. By testing the different approaches, the level of objectivity may be increased.

1.3 Research framework

This study consists of seven chapters. Figure 1.1 shows the flow of this study. The first chapter elaborated the history, frameworks, and the previous studies done in the field of LCA and LCC of Municipal Solid Waste Management (MSWM). Other existing models and a number of international guidelines were identified in this chapter. From the literature analysis it was found that the importance of real practice observation to identify the social aspects, organizational and institutional issues, economic aspects, and technical appropriateness. To response to this finding, our study conducted field observation, interviews with key persons and opinion survey to the local community. This effort of personalization is reflected thought the dissertation.

The second chapter provided the overview of the existing waste management practices and technologies in the region of developing countries in Asia. Based on the overview, a Strength, Weakness, Opportunity, and Threats (SWOT) analysis has been conducted to get a better understanding of the trend and practices in the region. The waste characteristics and trends, transportation, treatment technology, policies and regulation, as well as the existence of national or international program on MSWM especially in the field of composting and 3R are elaborated for the six selected countries: Indonesia, China, Thailand, India, Bangladesh, and Sri Lanka. These countries were selected because of their growing concern on waste management[27]. A brief explanation on each of the technologies was elaborated in this chapter to present a general technical understanding. Moreover, SWOT analysis of the MSWM practices in the developed European countries was also included for comparison.

The third chapter compared ELP methodology with Eco-Indicator 99 and Eco Point for validation of model selection and to examine how the weighting factors from the three models are different. The analysis was supported by an application to Jakarta MSWM scenarios for better understanding. The purpose of this chapter is not only to see whether ELP gives valid results as compared to the other methodologies but also to estimate the amount of environmental impact that may be avoided by the improved scenario which may be implemented in the future in the Jakarta integrated landfill site.

The fourth chapter consisted of the implementation of ELP methodology selected in chapter three to the 3 selected countries: India, Indonesia and China. These countries were selected for their high potential as the most populous developing countries and their potential of material and energy recovery from waste that has not yet been done optimally. The conclusion of four was, until the waste in the region is segregated, the practice of composting is still more feasible than anaerobic digestion because of its simple technology, medium environmental impact and lower investment cost[28].

[27] (Institute for Global Environmental Strategies, 2012)
[28] (Aye & Widjaya, 2006)

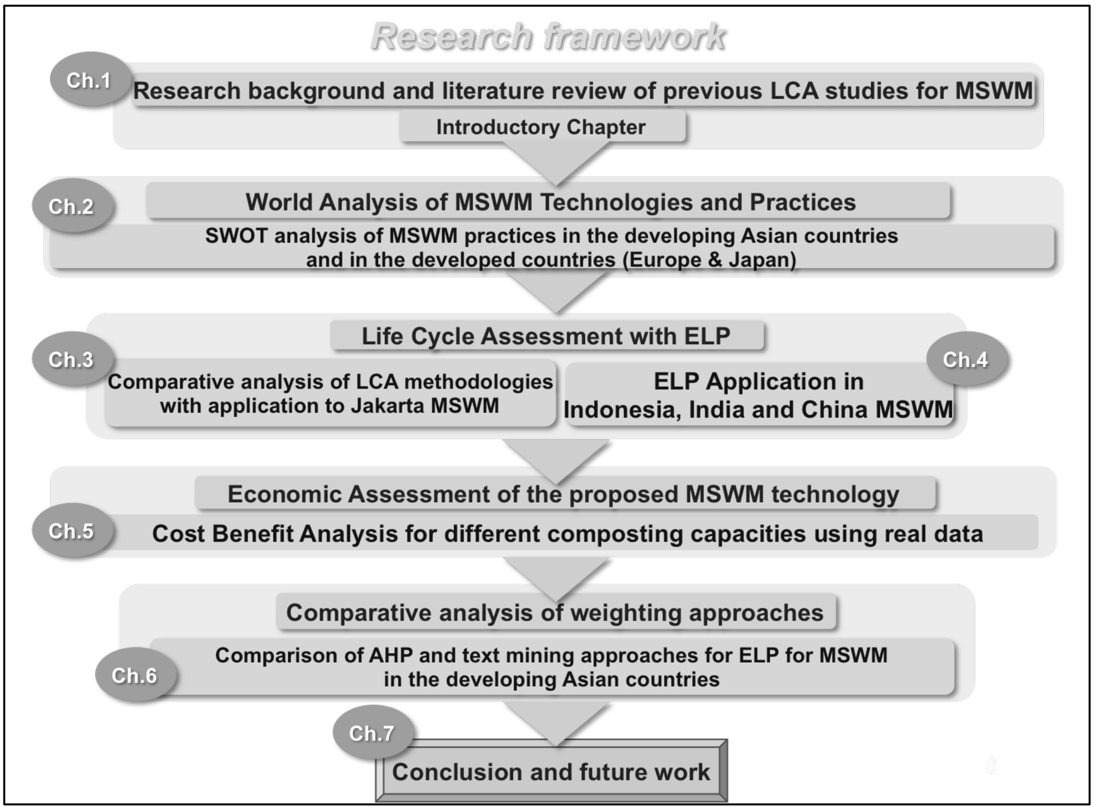

Figure 1.1 Framework of the study

Chapter five provided the suggestion for improvement of the currently existing composting plants. Another LCA of different composting scenario may give similar result in ELP/unit because the inventory data used would be the same, to avoid this, an economic feasibility improvement study using BCA was proposed instead. A BCA study of different scale of composting projects was conducted to find an optimum capacity of a composting plant. Five real operating plants in developing Asia represented the three different capacity of composting plant. The capacities were categorized into: small scale (0 to 50 Ton Per Day (TPD) capacity) composting plant, medium scale (50 to 400 TPD capacity) composting plant, and large scale (400 to 1000 TPD capacity) composting plant. The selected countries for small scale case study is Indonesia and Sri Lanka, the selected countries for medium scale case study is Indonesia, and the selected countries for large scale case study is China and Indonesia.

To give an alternative of weighting approach in the ELP methodology, this study presents and compares two different weighting approaches in chapter six. These are, Analytic Hierarchical Process (AHP) and text mining. By testing the different approaches, the level of objectivity may be increased and represent a wider scope of stakeholder opinion. Weighting values are given to 9 impact categories addressed in ELP. The 9 impact categories are; global warming, energy depletion, acid precipitation, ocean and water pollution, air pollution, resource consumption, waste disposal, ecosystem influence and ozone depletion. The result of text mining weighting approach showed higher attention in the field of waste disposal. Therefore, this approach may be useful in the future waste management ELP studies.

Chapter seven contained the conclusion of this study. Aspects of regulation and practices, environmental and economic assessment results, general remarks of what could be recommended were provided in this chapter. The way forward for MSWM in Asian developing countries were provided based on the conclusion of the study.

CHAPTER II

SWOT ANALYSIS OF MSWM PRACTICES IN THE DEVELOPING ASIAN COUNTRIES AND DEVELOPED COUNTRIES (EUROPE AND JAPAN)

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CHAPTER II

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2.1 Introduction

Adapting advanced technologies and management strategies for better municipal waste management in the developing countries could be very challenging, especially because there are many factors of uncertainties. These uncertainties may be the result of lack of understanding of the business as usual, community values and habits and regulations in the region. Just like any type of technology implementation in a new region, understanding the social and political situation of a country is as important as understanding technical information such as the different climate that affects varieties in temperature, humidity, waste characteristics, energy security, and the required human resources capacity. This chapter provides SWOT analysis of the MSWM practices in developing countries in Asia. Through SWOT analysis, the municipal waste trend and characteristics, regulatory frameworks, and technology appropriateness that are in practice in the region would be elaborated and analyzed for a better understanding. As comparison, SWOT analysis of the MSWM practices in the developed countries in Europe are also provided.

2.2 Description of the available MSWM technologies

The traditional method of municipal waste management, landfilling, is no longer desired due to its side effects such as pollution from leachate to the ground water, release of methane gas with 21 times global warming potential compared to carbon dioxide, permanent damage on the land which leaves the land as a hazardous waste for decades after rehabilitation, and social and ethical issues of scavengers working in such unsafe condition. The heat on the landfill that could reach to about 70° and there are risk that the scavengers are being knocked off by the excavators. More sustainable technologies should be implemented to treat solid waste. The rapid population and economic growth that lead to increase of waste generation, waste diversity, and land scarcity, add the urgency of decision makers to implement better strategies and technologies. The best way to manage waste is to go along with the waste management hierarchy, which is: avoidance, recovery, and only all of recovery failed, treatment and disposal may be conducted. This paper focused on the material and energy recovery part of the hierarchy by analyzing different waste treatment technologies.

The first part of this chapter analyzed some energy-efficient technologies for treating municipal solid waste. Energy – efficient in this context refer to the least possible energy required to treat solid waste and at the same time consider the energy recovery potential of the technology. This is due to insufficiency of electricity availability in many places in the developing Asian region. The technologies elaborated in this paper are composting, anaerobic digestion (AD), landfill gas (LFG) collection and Incineration. Majority of the municipal solid waste in the developing Asian countries has low calorific value (800 to 1000kcal/kg)[1], and high organic content (about 60%) are more favorable for biological processes such as composting and anaerobic digestion. Energy and capital intensive technology, such as incineration is less likely to be suitable for this region.

Taking into consideration the waste characteristics and the ongoing practices in the region, a Strength, Weakness, Opportunity, and Threats (SWOT) analysis is given at

[1] (Unnikrishnan, 2010)

the end of this paper to give a better confidence on deciding the best technology to be implemented in the developing Asian countries.
(Unnikrishnan, 2010)

2.2.1 Composting

The most commonly practiced solid waste management technology (aside from landfilling) in Asian region is composting. Composting is simple and it is one of the most known methods for recycling organic waste. There are several techniques for composting. The most practiced one are aerated windrow and vermin-composting.

Aerated Windrow

Windrow refers to the long row of piles of organic waste in an open area in the height of 1.25 meters to 3.25 meters that is the ideal height for the pile to maintain higher warmer temperature in the inner part of the pile. Every about 5 days, the pile is turned inside out / outside in, either manually or mechanically in order to ensure sufficient oxygen supply to maintain aerobic activity. The temperature inside the heap could rise up to 75 degrees Celsius and this ensures proper composting and killing the pathogens. For leachate catchment, concrete floor should be prepared under the windrow with less than 10^{-7}cm/sec permeability coefficients, 1 – 2% slope to allow the leachate to flow into the drains built surrounding the piles[2]. The whole process takes about 4 – 6 weeks and the quality of the compost rely not only to the optimum environment condition but also the composition of waste. Although food waste is desired for this process, meat and bones should not be used as it will attract unwanted germs and flies. Due to the simplicity of this technology, large scale (50TPD – 500TPD) of composting with this system is possible. The end product should have the dark brown soil-like color and texture, and sometimes, for better transportation and marketability, pelletization can also be applied before packaging.

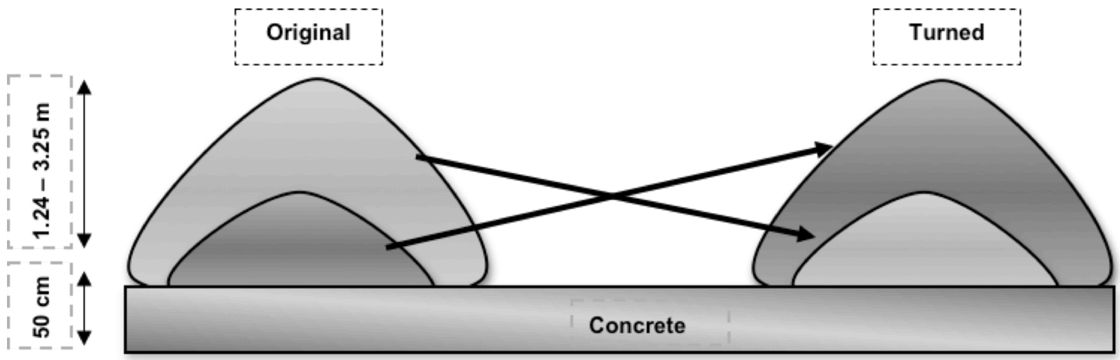

Figure 2.1 Open windrow composting pile-turning scheme

[2] (Dayalane, 2006)

Vermin-composting

Vermin composting is a composting technique that utilizes earthworm, working together with microorganism, as the composting agents. Organic waste and worms are put together in a bin and as the worm decompose the waste; nutrient-rich soil called castings will be released from the worm body. These castings contain 2 times richer in magnesium, 15 times nitrogen, and 7 times potassium compared to the surrounding soil[3]. Various techniques can be introduced in order to achieve better harvest such as substrate aeration, mixing, grinding, and water spraying to keep the ideal moisture content of 45 – 55%[4]. Utilizing local worms also help in the composting process as the local worm works best for the local temperature. For India case, the local worms that are good for vermin-composting are *Eudrilus euginae*, *Parionyx excavatus*, and *Eisenia fetida*. For every half a kilogram of organic waste, about 800 – 1000 worms are needed. The whole process takes up 3 to 4 months, and when the worms have eaten up all the waste, worms are removed; castings and worm tea are collected for fertilizer.

2.2.2 Anaerobic Digestion (AD)

Anaerobic Digestion, also called biogasification or biomethanation, is the anaerobic process of organic waste degradation with the assistance of microorganisms. This process is by far more efficient when compared to just collecting LFG because the waste is processed in a closed container with conditioned temperature and the absent of oxygen creates the optimal environment for biogas generation. A study shows that 1 ton of waste in a controlled anaerobic digestion produces 2 to 4 times of methane in 3 weeks in comparison to what 1 ton of waste in landfill will produce in 6 – 7 years[5]. The input of AD should contain relatively pure organic material and the output would be biogas with 55% - 60% CH_4 and 40 – 45% CO_2 that can be burned in the gas engine to generate electricity and the residue in form of digestate can be used as soil conditioner.

The flow of AD to generate energy from the organic waste (either sorted in the source or in MRF) is similar to the LFG capture. Methane gas is collected to be burned in the gas engine, excess heat can be recovered to electricity with Combined Heat and Power (CHP) and after self-consumption, and excess energy can be exported to the grid.

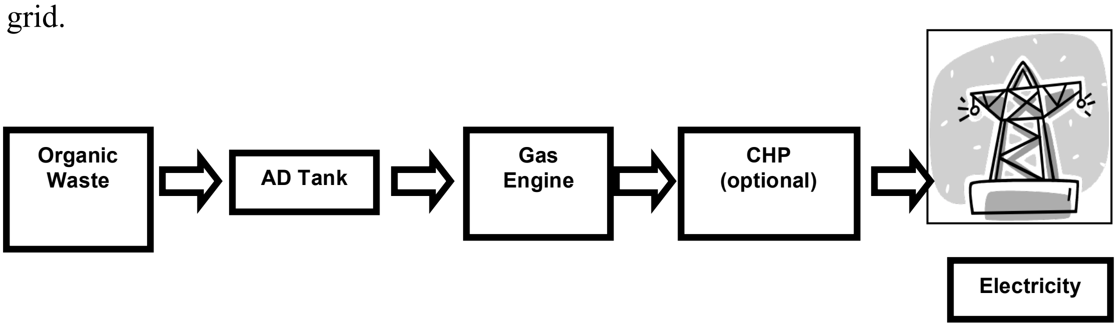

Figure 2.2 AD electricity generation scheme

There are four basic stages in AD; Hydrolysis, Acidogenesis, Acetogenesis, Methanogenesis. The first stage, hydrolysis, breaks down carbohydrates, fats, and

[3] (Kaviraj, 2003)
[4] (Singh, 2011)
[5] (Ahsan, 1999)

proteins into simple sugars, fatty acids and amino acids. The second stage, acidogenesis, further processes these molecules into Carbonic acids, alcohols, Hydrogen, Carbon dioxide, and Ammonia. The third stage, Acetogenesis, is the stage where acetic acids, hydrogen and carbon dioxide produced by acetogens (microorganisms that produces acetate) to allow the final stage where methanogens (microorganisms that produces methane) produce Methane and Carbon dioxide to be burned in the gas engine to generate electricity.

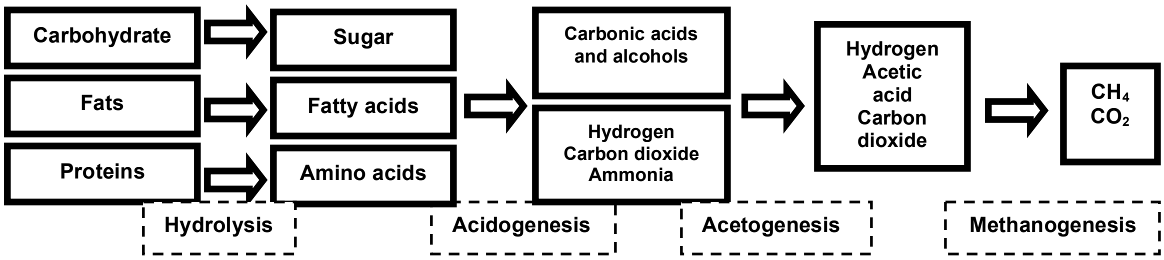

Figure 2.3 Four stages in the biogas generation

Based on the type of methanogen utilizes in the digester, the process can be done either in mesophilic temperature (30-40 °C) or in thermophilic temperature (50 – 60 °C)[6]. The mesophilic one is more stable because it can still work in ambient temperature (20-45 °C) therefore it requires less energy to operate.

The digestion process can be done at once or in multiple stages. The one-stage process has lower capital investment, but less optimal productivity due to its inability to create pH or better control for the microorganisms to work efficiently. The multiple stage digesters yield more gas but takes longer retention time. The disadvantage of AD technology is the relatively long retention time compared to the other technologies. Based on various case studies, retention time for AD ranges from 8 – 21 days.[7]

AD is quite common in India, especially for small-scale biogas plants with animal slurry as input. But municipal waste AD is also practiced such as the 14 MW capacity AD plant in Naghpur, Maharashtra.

This technology is recognized as one of the renewable energy options and especially helpful to provide energy considering the scarcity and high GHG emission of petrol based energy. Burning biogas from organic waste as a way of electricity generation is counted as an emission neutral practice since organic materials basically have absorbed CO_2 from the atmosphere and energy from the sun in order to grow. Organic waste is one type of biomass. The definition of biomass is biological material from living or recently living organisms. Fossil fuel in the other hand is not counted as biomass because it has gone through geological processes into the form of coal and petroleum. The replacement speed of petrol-based fuel by far cannot compete with organic waste. AD as renewable energy is also justified by the fact that it is one of the projects that could be registered as a Clean Development Mechanism (CDM) project.

6 (Sambo, 1995)

7 (Shekdar, 2004)

2.2.3 Landfill gas utilization (LFG)

Landfill gas contributes to about 10% of the global warming due to the high methane gas global warming potential. Capturing methane gas from a landfill allows energy generation as well as reducing global warming. Even without energy generation, flaring LFG reduces the potential by 21 to 23. The gas produced in the landfill is the result of degradation of Municipal Solid Waste (MSW) by microorganisms. The quantity and quality of yielded gas depends highly on the waste composition, presence of oxygen, temperature, physical geometry, and time elapsed since disposal time. The desired composition of waste is the organic waste such as kitchen waste since they release more gas. When oxygen does not present, microorganisms could degrade the waste better and the more yield of gas is generated. In the absence of oxygen, biogas generated contains of about 50% CO_2 and 50% CH_4. Methane gas (CH_4) is the more desired type of gas since its high calorific value (33.95 MJ/Nm^3)[8] , this means it generates more electricity. Since the existence of oxygen leads to aerobic process instead of anaerobic, the gas produced in the presence of oxygen results in higher CO_2 content instead. The longer time elapsed since disposal means the deeper the waste has gone under the pile and the less oxygen exist, thus the better anaerobic condition is created and the higher CH_4 is released. The gas is captured at the relatively lower part of the landfill by flowing it through the well, to the pipe and finally to the plant to run the gas engine to produce electricity. When the amount of gas exceeds the engine capacity, it would be flared to prevent engine malfunction.

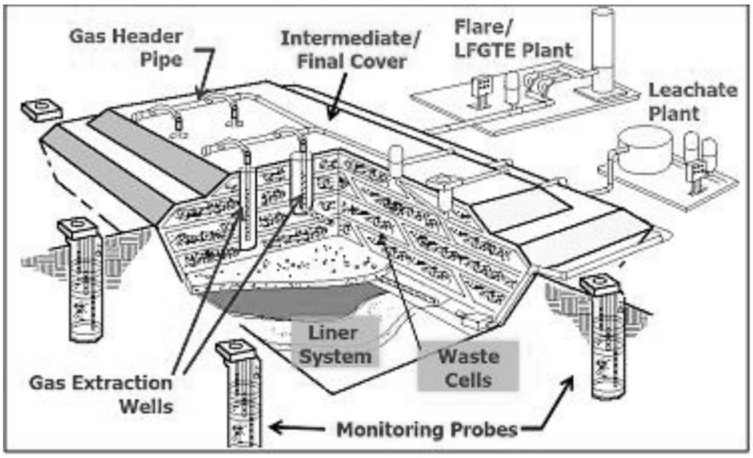

Figure 2.4 Landfill gas collection system

Source: U.S. Environmental Protection Agency 2009

[8] (UK Environment Agency, 2002)

The capacity of a gas engine that is used for LFG ranges from 330 kW to 3 MW with efficiency from 38% to 44% of electricity generation[9]. This technology is practiced in Jakarta's Landfill (Bantargebang) with waste input of 4000 to 6000 Tons per Day (TPD), using a *Jenbacher* gas engine by *Clarke Energy, General Electric* with electrical output of 2MW. Waste characteristic of Jakarta is relatively similar to the other developing Asian countries since it is a mixed waste containing about 60% of organic content. However, the landfills in India, for example, are less scientific when compared to the Jakarta one which probably hinders the practice of this technology since it requires a sanitary landfill with proper leachate catchment and gas control systems[10]. Therefore, this technology could be applied for cities that opt for building sanitary landfills due to low immediate budget. Although in fact, in the long term, landfill is a very expensive option when rehabilitation cost and externalities of all the damage it causes are taken into account. The average lifetime of a landfill is 20 years but the rehabilitation period may require more than 60 to 80 years.

To improve efficiency of energy recovery from landfill gas, the generated heat (which often higher than the electricity generation) when utilized with Combined Heat and Power (CHP) technology, electricity output can be increased. A more simple approach can also be applied to utilize the heat, which is direct use for the leachate treatment plant. This has been practiced in Cavenago landfill, Italy. By conducting this approach, the Cavenago LFG recovery was able to sustain the whole landfill site energy requirement. Another case study from is from Doncaster landfill in UK. The engines still work well when the methane content in LFG drops to as low as 35%. LFG collection Bantar Gebang landfill in Jakarta shows that the methane content is about 50% in average therefore technically it should be more stable when practiced in the high organic content landfills.

2.2.4 Incineration

Incineration technology allows the reduction of solid waste volume by 95% by combusting them. This technology is favored in land-scarce countries like Japan and very efficient in treating medical and hazardous waste. However, this technology is capital intensive and the flue gas has to be very carefully monitored in order to avoid emissions such as dioxin and mercury that could harm human health. The modern incineration are equipped by flue gas cleaning system to make sure the chemical components in the flue gas has meet the standard made by the country. However, the flue gas cleaning system itself is very cost intensive to the point where it cost more than the rest of the incineration plant. By attaching Combined Heat and Power (CHP) technology, energy recovery is possible. But attempt of gaining revenue from an incinerator can only be achieved, in most cases, when the waste has high calorific value and have a sustainable input of waste reaching over 100,000 tons of waste annually and relatively constant calorific value of 8MJ/kg (1912 kcal/kg) all year round[11].

There are several types of incineration such as the moving grate, fixed grate, rotary-kiln, and fluidised bed. The common one that is used to treat municipal solid waste is the moving grate. This system start with waste trucks dumping the waste into a deep

9 (Clarke Energy)

10 (S. Unnikrishnan, 2010)

11 (World Bank, 1999)

pit followed by cranes that functions to pick up the waste and deliver it to the reception of the grate that will move and transfer the waste to the furnace to be combusted. There are two combustion stages to ensure complete combustion of the waste. The second combustion stage includes turbulence to ensure oxygen sufficiency and better mixing. The flue gas that comes out of the combustion has to be further combusted to make sure that the toxic are very well break down. The European Waste Incineration Directive requires flue gas from incinerators to be burned above 850°C for 2 seconds to meet this purpose.
The next stage would be using the flue gas in the steam engine in order to create steam to run the turbine for power generation. In this way, electricity generation is possible. The last but most crucial stage is the flue gas cleaning, to ensure that the plant meets the emission regulation. The bottom ash, which is the noncombustible remaining from the incineration is then either landfilled or fed in to the cement kiln for concrete or road constructions while the portion of the ash that flew to the air is called the fly ash

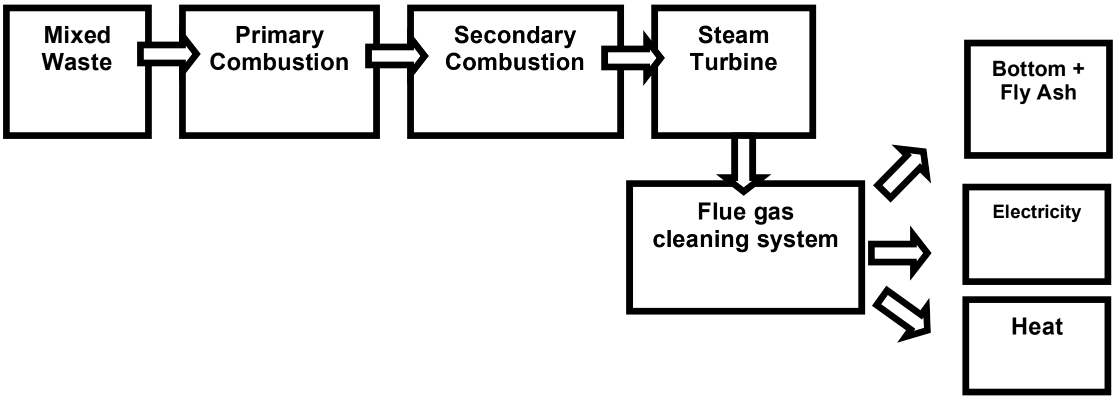

Figure 2.5 Moving grate incineration system

2.3 SWOT Analysis of MSWM practices

2.3.1 In the developing Asian countries

Municipal Waste generated per capita per day in the developing Asian region is quite diverse. The lowest one is in the smaller states of India such as Manipur and Tripura with around 0.2 kg/capita/day. Accordingly, the bigger cities have higher waste generation per capita per day such as Gujrat and Delhi. China has the biggest generation of 1.54 kg/capita/day, which is about three fold of the other countries' average in this study. China's figure is similar with OECD countries of 1.53 kg/capita/day. One factor that influences the waste generation per capita is the percentage of urban population, which is over 38% in China and over 28% in India[12].
The growth per year is also very diverse, Thailand with 4% a year, in contrast with Bangladesh of 27.5% a year. The collection rate ranges from 28% in China to 72.5% in India. Thailand, India, and Bangladesh allocate quite a decent percentage of its municipal budget for Waste Management, ranging from 5 to 37%, on the other hand, Indonesia and Sri Lanka allocate less than 5%. With this allocation rate however,

[12] (Visanathan & Trankler, 2003)

Indonesia manages to collect slightly higher percentage of waste than Thailand. India collects an outstanding 72.5% of its municipal waste heading far beyond the rest of the countries. Table 2.1 summarizes the Municipal Waste generation, growth, collection rate, and percentage of the municipal expenditure allocated for waste handling.

Table 2.1 Municipal Waste generation and collection rate in the 6 developing Asian countries

Country	Waste generated per capita per day (kg)	MSW growth (% per year)	MSW collection rate (%)	Expenditure from municipal budget (%)
Indonesia	0.375 to 0.450	NA	40.09	0.59 – 3.65
Thailand	0.65 to 1.08	4	38	37
China	1.54	10.48	28	NA
India	0.2 to 0.5[13]	NA	72.5	5 to 25[14]
Sri Lanka	0.4 to 0.8	NA	39.5	3.15[15]
Bangladesh	0.325 to 0.485	27.5	55	5 to 20

Source: IGES interim reports 2012

Table 2.2 Municipal Waste generation and recycling rate in the 6 developing Asian countries

Country	MSW Annual Generation (Ton)	Population	Population growth (%)	Recycling rate (%)
Indonesia	38.5 million	232.7 million	1.07	30 (estimated)
Thailand	16.79 million	70 million	0.56	11
China	1.8 billion	1.3 billion	0.47	25
India	66.69 million	1.2 billion	1.41	
Sri Lanka	2.34 million[16]	21.5 million	0.86	
Bangladesh	3.75 million	142.3 million	1.50	26 (estimated)

Source: IGES interim reports 2012

Table 2.3 Type of Municipal Waste composition in 6 Asian developing countries

Country	Type of Municipal Waste Composition (in%)					
	Organic waste*	Paper	Plastic	Metal	Glass	Others**
Indonesia	62	9	14	2	2	10
Thailand	57.53	8.55	13.59	3.52	4.3	12.51
China	63.4	11.7	12.7	0.27	1.76	9.03
India[17]	41.8	5.7	3.9	1.9	2.1	44.6
Sri Lanka	77.24	6.47	5.91	2.76	2.03	5.57
Bangladesh	76.3	9.1	3.5	1.5	0.8	8.8

Source: IGES interim reports 2012

[13] (Sharholy, M, et al., 2008)
[14] (National Solid Waste Association of India)
[15] (Visanathan & Trankler, 2003)
[16] (UNEP, 2001)
[17] (CPCB, 2000)

* Organic waste is including kitchen waste, paddy husk, and wood waste
** Other waste is including dust, leather, rubber, textile and inert waste

Legal frameworks on Municipal Waste

A few of the developing Asian countries has a dedicated law on MSWM while the others only provides standards on pollutant or technical guidelines for MSWM technology adoption. For example, Indonesia has Act of the Republic Indonesia Number 18 Year 2008 regarding waste management and India has Municipal Solid Waste (Management and Handling) Rules, 2000. These regulations cover all types of waste and regulate appropriate approaches in handling them. In Thailand, SWM is regulated mainly under the Public Health Act A.E. 1992 (2535) that contains explanation on SWM related definitions and the National Environmental Quality Act B.E. 2535 (NEQA 1992) that contains pollution standards. China's law and regulations are more technological specific such as standards for landfills and incineration. Sri Lanka has an established national SWM support center since 2007 to assist on SWM related action plans based on the National Strategy of SWM which contains the promotion of 3R activities and a regulation on pollutant standard in compost from MSW and agricultural waste. Bangladesh emphasizes the importance of resource recovery in the national sanitation strategy and promotes of the use of organic waste materials for composting and anaerobic digestion under the national policy for water supply and sanitation. Table 2.5 lists the existing municipal waste regulations and laws in each country and the institution or governmental body in charge.

Table 2.4 Laws, regulation, and institution or governmental body in charge

Country	Law / regulations on Municipal Waste	Institute / Governmental body in charge
Indonesia[18]	- Act of the Republic of Indonesia Number 18 Year 2008 regarding Waste Management - Law Number 38 year 2007 regarding Responsibility of Central Government, Provincial Government and Local Government - Act of the Republic of Indonesia Number 23 Year 1997 regarding Environmental Management - Law Number 26 year 2007 regarding Spatial Planning - Government Regulation Number 21 year 2006 regarding Policy and Strategy of MSW - Government Regulation Number 16 year 2005 regarding Water Supply (Raw Water Protection) - Law Number 32 year 2004 regarding Local Government - Law Number 7 year 2004 regarding Water Resources - Law Number 23 year 1992 regarding Health	- Ministry of Environment is responsible for providing national policy - Ministry of Public Work together with MOE, MOT, MOI, BPPT and Ministry of Home Affair are responsible for preparing guidelines of MSW - Local Government is responsible for local operations of MSW management (Indonesia is implementing a program on municipal waste management called "Clean City Program/ADIPURA AWARD)

[18] (AIT/UNEP, 2010)

Thailand	- Rules on waste separation at source - Criteria, standards and procedure for managing infected waste - The enhancement and conservation of National Environmental Quality Act, 1992 on requirements over the procedures for collection and transportation of community hazardous waste - Registration of operators in the business of waste management and setting operational guidelines - The Town Planning Act, 1975 for mandatory requirement of areas used as site for integrated waste disposal center - The Public Health Act, 1992 and The Enhancement and Conservation of National Environmental Quality Act, 1992	- Pollution control department provides definitions, guidelines and standards for waste minimization - Department of Environmental Quality Promotion - Office of Natural Resources and Environmental Policy and Planning - Department of Local Administration - Public Health Department
China[19]	- Law on the Prevention an Control of Environmental Pollution by Solid Wastes, effective 2005 - Standard for Pollution Control on the Landfill Site for Municipal Solid Waste (GB16889-2008), effective July 2008 - Standard for Pollution Control for Municipal Solid Waste Incineration (GB18485-2001), effective January 2002 - Technical code for municipal solid waste sanitary landfill (CJJ17-2004), effective June 2004 - Technical Standard for Solid Waste Cleaning of Reservoir Bed on The Three Gorges on Yangtze River (HJ85-2005), effective June 2005 - The control standards for urban wastes for agricultural use (GB 8172 – 87), effective February 1998 - Regulations for the Administration of Prevention of Pollution of the Yangtze River water are by ship's garbage and littoral solid wastes, effective March 1998 - Regulations of the City's Appearance and Environmental Sanitation, effective August 1992 - Notice of Limitation of Production, Distribution and Use of Plastic Shopping Bag, effective June 2008	- Ministry of Environmental Protection - State Environmental Protection Administration - Ministry of Construction - State Council Three Gorges Project Construction Committee Executive Office - Ministry of Communications - State Council
India	- Municipal Solid Waste (Management and Handling) Rules, 2000 - Recommendations of the Committee constituted by Supreme Court of India for SWM in Class I cities in India, 1999 - Fertilizer (control) Amendment Order, 2006, followed by Fertilizer (Control) Third Amendment Order, 2009 – for quality control of compost from MSW - National Environment Policy, 2006	- Ministry of Environment and Forests - Constitution of the Technology Advisory Group - Inter-ministry constitution

[19] (AIT/UNEP, 2010)

	- Road Map of Management of Waste in India, 2010 - Integrated Plant Nutrient Management using City Compost report of inter-ministerial task force, 2005 - Environmental Impact Assessment Notification, 2006	
Sri Lanka	- National Strategy on Solid Waste Management, 2000 - Standards for compost production from municipal solid waste and agricultural waste (Sri Lanka Standard 1246:2003, UDC 628.477.4)	- Local Government - Provincial Councils - Ministry of Environment - Ministry of Agriculture (Sri Lanka established National Strategy for Urban Solid Waste Management and created National SWM Support Center to assist action plans formulation and implementation)
Bangladesh	- Environment Conservation Act 1995 - Environment Conservation Rules 1997 - National Environmental Management Action Plan (NEMAP) - Urban Management Policy Statement, 1998 - National Policy for Water Supply and Sanitation 1998 - National Clean Development Mechanism (CDM) strategy 2005 - National sanitation strategy 2005 - National Renewable Energy Policy 2008	- Ministry of Environment and Forest

Sources: AIT/UNEP 2010, IGES interim reports 2012

Table 2.5 Situation of the existing MSW technologies and treatment plants in the region

Country	Landfill	Anaerobic digestion	Composting facility	RDF	Incineration Facility	Other
Indonesia	68.86% are landfilled, only 10% of the landfill are sanitary landfill		7.19 % of the Municipal Waste are composted		4.49% are burned in the open space, 6.59% are burned in small scale incineration plant	2.99% of the waste are dumped into the river, 9.58% are buried
Thailand	37.99% of waste generated are delivered to the sanitary landfill, 62% are open dumped. There are 94 sanitary landfill available	1.6% of waste generated are composted and anaerobically digested			There are 2 incineration plants in Thailand	There are 3 Integrated Solid Waste disposal sites
China	56.6%		12.9%		1.9%	

India	- Non existence of sanitary landfill makes landfill gas capture technology unfeasible - open dumping is common	Unsuccessful large scale AD plants in Nagpur, Lucknow, Vijaywada (20TPD*), and Koyambedu flower market (30 TPD) due to low quality input	Vermi-composting and aerobic windrow composting are practiced in clusters, product quality is not optimal	Unsuccessful RDF plants in Deonar, Mumbai(80 TPD), Bangalore (5 TPD), Hyderabad (700 TPD), Vijaywada (600 TPD) due to low calorific value	- Unsuccessful incineration plant in Timarpur (300 TPD) - Two on trial incineration plant in Delhi (1950 TPD) and (1300 TPD)	Bio – mining activities from old open dumpsites to produce soil enricher is trending
Sri Lanka	The common practice is open dumping	Unsucessful AD plant in Kirulapone due to low gas generation and management issues	70 composting plants in operation, 90% are small scale (<10TPD capacity), 10% is medium scale (up to 50 TPD)		Not suitable due to high moisture content and low calorific value	
Bangladesh	Open dumping is the common practice				Not suitable due to high moisture content and low calorific value	

* TPD : Ton Per Day
Source: IGES interim reports 2012, ADB interim reports 2011

The development of 3R activities and CDM projects in the region

The 3R activities are promoted throughout the region, mainly done in the community level such as schools and community centers. The activities are including collecting recyclable materials and the banning of unsustainable practices such as plastic bags and unnecessary packaging. The collection of recyclables enable waste separation therefore composting activities become easier to be done in parallel with composting like what is done in Sri Lanka's *Pilisaru* project.

Table 2.6 The situation and development of 3R activities in the region

Country	Development of 3R activities
Indonesia	- The Ministry of Public Works started 3R activities since 2006, it is taking place in 200 locations in 150 cities - The State Ministry of Environment implements 3R activities in the following regions: • *Singaparna, Tasikmalaya* regency (West Java province) • *Jombang* regency (East Java province) • *Magelang* city (Central Java province)

Thailand	- Pollution Control Department (PCD) under the Ministry of Natural Resources and Environment provides guidelines for reduction and minimization of waste, at-source separation, recycling and reusing methodology and implementation strategies - The Ministry of Natural Resources and Environment implemented 3R programs such as: • Reduction of the use of plastic and foam in department stores • Voluntary programs for packaging waste recovery • Pilot projects for MSW recycling • Capacity building for the local government - The Ministry of Science, Technology and Environment (MOSTE), Department of Environmental Quality Promotion (DEQP), and Thailand Institute of Packaging Management for Sustainable Environment (TIPMSE) had been promoting recycling programs such as: • School Garbage Bank (SGB) in more than 500 schools • University Garbage Bank • Community Garbage Bank (CGB) in more than 80 communities • Recyclable waste drop-off center in 9 department stores and 43 supermarkets • Waste collectors group with about 200 members • Recyclable waste collection project in housing estates
China	China is promoting Circular Economy principal where it focuses on strategies for creating a circular flow of materials, and energy flows such as by providing economic measures that are favorable to 3R practices.
India	Recycling is emphasized in MSW 2000 Rule Schedule II, SI. No.5 including recommendation if appropriate waste management for example by using the following technologies: • Composting plus Refuse Derived Fuel (RDF) as a combination for optimal use of resources and minimization of landfill space • Waste to energy by RDF and Solid Recovered Fuel (SRF) • Waste to energy by Anaerobic Digestion (AD) • Use of recycled material • PET bottle recycling • Banning of plastic bags in Delhi
Sri Lanka	- The promotion of 3R approach is reflected in the National SWM strategy - The Central Environment Authority under the Ministry of Environment established a national level 3R project called *Pilisaru* project in 2008
Bangladesh	- The Ministry of Environment and Forest (MoEF) using its Climate Change Trust Fund initiated 3R Pilot projects to reduce Green House Gas (GHG) emission in • Dhaka and Chittagong cities (2010 to 2011) • In 64 cities of Bangladesh (2010 to 2017) - UNICEF promotes 3R activities in 19 towns of Bangladesh with carbon financing (2009 to 2011) - MoEF supported by United Nations Development Programme initiated a community based SWM program called Sustainable Environment Management Programme (SEMP) with focus on composting and 4R implementation

Source: AIT/UNEP 2010, ADB consultants 2011, IGES interim report 2012

The large scale MSWM CDM projects in the region are dominated with Landfill Gas (LFG) capture for energy recovery. This is due to the big number of landfill existing in the region and the rather simple technology compared to RDF or Incineration, supported by the high amount of organic waste that results in high methane gas released from the landfill.

Table 2.7 Existing Large Scale Municipal Waste Management CDM projects in the region

Country	Existing CDM Projects	Technology	Capacity	Year of registration
Indonesia	PT Navigat Organic Energy Indonesia Integrated Solid Waste Management (GALFAD) Project in Bali, Indonesia	LFG	9.6 MW	2007
	Pontianak – GHG emission reduction through improved MSW management – LFG capture, Flaring and Electricity Generation	LFG	200 TPD	2008
	Gikoko Palembang – LFG Flaring Project	LFG	296 TPD	2009
	Gikoko Bekasi LFG Flaring Project	LFG	2900 TPD	2009
	Gikoko Makassar – LFG Flaring Project	LFG	452 TPD	2009
	Piyungan Landfill Gas Capture Project in Yogyakarta	LFG	10 MW	2010
	Bionersis LFG Project Indonesia 2: Batam	LFG	1 MW	2011
Thailand	Bionersis Project Thailand 1	LFG	2 MW	2009 (registered) 2011 (CER issued)
	Jaroensompong Corporation Panomsarakham Landfill Gas to Energy Project	LFG	1.02 MW x 2 units	2009
	Chiang Mai Landfill Gas to Electricity Project	LFG	1.26 MW x 3 units	2009
	Bangkok Kamphaeng Saen East: Landfill Gas to Electricity Project	LFG	1.063 MW x 9 units	2009
	Bangkok Kamphaeng Saen West: Landfill Gas to Electricity Project	LFG	6 MW	2011
	Active Synergy Landfill Gas Power Generation Project Nakhon Pathom	LFG	1 MW	2010
	Rak Baan Rao (RBR) Integrated Municipal Solid Waste	LFG	500 kW x 12 units	2010

	Management and Utilization Facility			
	Jaroensompong Corporation Rachathewa Landfill Gas to Energy	LFG		2008
China	Nanjing Tiangjingwa Landfill gas to electricity Project	LFG	6 MW	2005
	Meizhou Landfills Gas Recovery and Utilization as Energy	LFG	2 MW	2006
	Anding Landfill Gas Recovery and Utilisation Project	LFG	75,557 t CO2 annual avoidance (Estimated)	2006
	Wuxi Taohuashan Landfill Gas to Electricity	LFG	2.06 MW	2007
	Shenzhen Xiaping Landfill Gas Collection and Utilization Project	LFG	8.5 MW	2007
	Jinan Landfill Gas to Energy Project	LFG	2.06 MW	2007
	Composting of organic waste in Wuzhou	Composting	90.520 TPY	2007
	Guangzhou Xingfeng Landfill Gas Recovery and Electricity Generation CDM Project	LFG	19 MW	2007
	Jiaozishan Landfill Gas Recovery and Utilisation Project	LFG	3 to 4.5 MW	2007
	Nanning Landfill Gas to Energy Project	LFG	3.85 MW	2008
	Mianyang Landfill Gas Utilsation Project	LFG	500 kW x 4 units	2008
	Kunming - Wuhua Landfill Gas to Energy Project	LFG	3.3 MW	2008
	Tianjin Shuangkou Landfill Gas Recovery and Electricity Generation	LFG	800 to 1000 TPD	2008

	Fuzhou Hongmiaoling Landfill Gas to Electricity Project	LFG	2.5 MW	2008
	Kunming Dongjiao Baishuitang LFG Treatment and Power Generation Project	LFG	3.3 MW	2008
	Shenyang Laohuchong LFG Power Generation Project	LFG	3 MW	2008
	Xiamen Dongfu Landfill Gas-to-Energy Project	LFG	3.5 MW	2009
	Municipal Solid Waste (MSW) Composting Project in Urumqi, China	Composting	600 TPD	2009
	Liaoning Landfill Gas Recovery and Utilization Project	LFG	700 TPD	2009
	Luoyang Landfill Site LFG Recovery to Electricity Project	LFG	1.5 MW	2009
	Dalian Maoyingzi Landfill Gas Recovery for Power Generation Project	LFG	4 MW	2009
	Nanchang Maiyuan Landfill Gas Recovery and Utilisation Project	LFG		2009
	Controlled combustion of municipal solid waste and sewage sludge and energy generation in Shaoxing City, People's Republic of China	Incineration	12 MW x 4 units	2009
	Hunan Loudi Miaopu Landfill Gas to Power Project	LFG	1.04 MW	2009
	Shenyang Daxin Landfill Gas to Electricity Project	LFG	10 MW	2010
	Hefei Longquanshan Landfill Gas Power Generation Project	LFG	3 MW	2010
	Huzhou Municipal Solid Waste Incineration for Power Generation Project	Incineration	15 MW	2010

	Suzhou Landfill in Anhui Province Gas Utilization Project	LFG	1MW	2010
	Shandong Qingdao Xiaojianxi Landfill Gas Utilization Project	LFG	1.063 MW x 3 units	2010
	Chengdu Luodai Municipal Solid Waste Incineration Project	Incineration	12 MW x 2 units	2010
	Huizhou Landfill Gas Recovery and Utilization Project	LFG	3 MW	2010
	Hanyang Municipal Solid Waste Incineration for Energy Generation Project in Haining City	Incineration	7.5 MW	2010
	Guangdong Shenzhen Laohukeng Landfill Gas Utilization Project	LFG	1.063 MW x 3 units	2011
	Changshu Municipal Solid Waste Incineration Project	Incineration	12 MW	2011
	Changchun City Landfill Gas Power Generation Project	LFG	3 MW	2011
	Wuhan Liufang Landfill Gas Recovery as Energy Project	LFG	500 kW	2011
	Huangshi Landfill Gas Recovery for Power Generation Project	LFG	1 MW	2011
	Wuhan Xinzhou Chenjiachong Sanitary Landfill LFG Power Generation Project	LFG	3 MW	2010
	The Chengdu Jiujiang Municipal Solid Waste Incineration Power Plant Project	Incineration	18 MW x 2 units	2011
	Yangzhou City MSW Incineration Power Generation Project	Incineration	9 MW x 2 units	2011
	Anyang Tanggou MSW landfill site LFG recovery to power project	LFG	500 kW x 6 units	2011

	Hunan Changsha Qiaoyi Landfill Gas Recovery and Electricity Generation Project	LFG	1 MW x 6 units	
	Nanhai MSW Incineration II Project	Incineration	15 MW x 2 units and 20 MW x 2 units	
	Zhoushan MSW Incineration Power Generation Project	Incineration	7.5 x 2 units	
	Zhuzhou Landfill Site LFG to Power Generation Project	LFG	3 MW	
	Hangzhou II Landfill Gas Power Generation Project	LFG	1 MW x 6 units	
India	The TIMARPUR-OKHLA Waste Management Company Pvt Ltd's (TOWMCL)	RDF + AD	1300 TPD in Okhla + 650 TPD in Timarpur for RDF, 100 TPD for AD. 16 MW	2007
	Integrated Municipal Waste Processing Complex at Ghazipur, Delhi	RDF	10 MW	2008
	Installation of Bundled Composting Project in the state of Tamil Nadu	Composting	545 TPD	2009
	Gorai Landfill closure and Gas Capture project, Mumbai, India	LFG	1200 TPD	2009
	Bundled Waste Processing Facilities in India	Composting	600 TPD	2009
	Expansion of Nature and Waste Bhalaswa Composting Plant at Delhi	Composting	135 TPD	2010
Bangladesh	Landfill Gas Extraction and Utilization at the Matuail landfill site, Bangladesh	LFG	20 MW	2005
	Composting of Organic Waste in Dhaka	Composting	700 TPD	2006

Source: UNFCCC database 2010 to 2012

Energy recovery potential of MSWM technology options

Composting consumes process energy but not producing any energy in a usable form. The German Government report a typical energy consumption of from 20 to 50 kWh/ton of waste treated. This range of energy consumption varies based on the size of the composting plant and the maturity of the compost produced[20].

Anaerobic digestion both consumes and recovers energy during the process. The energy recovered is in the form of heat and biogas that can be burned in the gas engine to produce electricity. The plant can sustain itself by using about 35% of the gross electricity produced and the rest of the electricity can be exported to the grid[21]. The more efficient process of anaerobic digestion is the thermophilic process that requires higher temperature (50 to 60 °C) and this heat can be self-provided by the plant itself too. In warmer climate regions, this process is made more efficient. The mesophilic process (30 to 40 °C) however, is more stable and requires less energy.

RDF is very energy intensive, not only for the energy it require to dry out the waste but also for running the pellet mills and these pellets has to be further cooled down for storage and heat produced from compression[22]. When fed in to the coal power plant however, the combination of 70% coal 30% RDF gives a more suitable fuel for the power plant energetically but releases a more undesirable toxic in the ash and flue gas. By applying the right flue gas scrubbing technology, using higher sulfur content coal and metal recovery from ash may allow dioxin avoidance and give a better incentive.

The other reason why incineration is not very much practiced in the developing Asian region is to high organic content (40 to 60%), high moisture content (40 to 60%) high inert content (30 to 50%) which are the cause of the low calorific value (800 to1100 kcal/kg) in MSW. In practice, an attempt on building incineration plants in India has shown negative result; incineration plant in Timarpur, Delhi (1988) closed down after few months of operation. The other threat for incineration is the scavengers (approximately 100,000 people in Delhi) collect the high calorific value waste such as plastics that are necessary for the incineration plant efficiency.

In the situation where waste is segregated at source, optimal energy recovery from pure organic waste may be gained by AD. This technology has been working very well in Asian region especially in Indian cities in smaller scale with animal manure and kitchen waste as input. There is one registered CDM project on small-scale biogas plant (2 m2) in attempt to provide 18,000 plants to support the poor families in Bagepalli, India so that they can sustain their needs of energy for cooking purposes by feeding the biogas digester. However, on the large scale of biogas using domestic waste is still not widely practiced since the technology is not yet proven in developing countries. For large scale AD utilizing municipal solid waste, additional unit such as the mechanical pre-sorting plant should be prepared in order to gain the organic waste (MBT system), but this would mean more energy required to run the system. The other approach is to manually sort the waste before feeding in to the AD plant, but this would mean exposing human to potentially hazardous waste. An option for applying AD technology in Asian region context could be the community participation one where AD is done in small scale.

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[20] (White, 1999)
[21] (White, 1999)
[22] (White, 1999)

2.3.1 In the developed European countries and Japan

European approaches on handling solid waste are gaining more attention along with the importance of GHG emission abatement and priority on renewable energy. Driven by these motives, EU countries have developed leading technologies in waste to energy. On the other hand, Japan has long practiced incineration and recycling. The integrated approach on handling waste is also shown by the growing "eco-town" practices in Japanese industrial area where recycling of different kinds of materials are being done in one site.

European developed countries

The latest European Union (EU) regulation on waste is New Waste Directive 2008/98/EC (EU, 2008) which gave new definitions for waste, by-products and end-of-waste in addition to the hierarchical system based on four subsequent levels (EU, 2006). In summary, each of waste categories (packaging, end-of-life vehicles, electrical and electronic equipment, batteries, graphic paper, commercial waste, waste wood, and waste oil) has to be treated in line with the waste management hierarchy: (1) Avoidance, (2) Reuse, (3) Recovery of material, (4) Recovery of energy, (5) Environmentally sound disposal. The common tool used to determine which technology to be applied in EU is Life Cycle Analysis (LCA) which considers collection, shipping, treatment, recycling and disposal. This comprehensive analysis goes hand in hand with the Environmental Impact Assessment (EIA) to make sure that the chosen technology is environmentally appropriate to be applied in the site.
Composting plants that are still in operation in Europe developed as early as in the 1960's. The so called "bio waste" which contains of garden and kitchen organics from households are collected separately from "rest waste" which is mainly the rest of the waste excluding recyclables. The bio waste is composted centrally, mainly by aerobic systems, with the compost having a short retention time in a reactor or pre-composter and a longer time in aerated static piles. Windrow composting is less common but does exist. The earliest attempt of composting in European countries was to compost mixed waste, which only result in both contaminated organic materials and contaminated recyclables that are downgrading the values of both resources. Mixed waste composting now only exists in several countries such as Spain and Greece. The second attempt was to implement wet-dry composting which led into confusion of dry organics and wet inorganics. The attempt did not result in any better quality of compost. The third attempt was by separate collection of organics where only yard, garden and kitchen waste are collected for transfer in centralized composting facilities. This model is adopted in countries such as Denmark, Germany and the Netherlands and growing in other European countries[23].
Larger scale Anaerobic Digestion in Europe increased in the last few years mainly driven by the guaranteed subsidy for renewable energy and attractive feed-in-tariff. The inputs are both household and commercial waste such as food waste and organic waste from production processes which are separated at the source. The commonly used technology is the wet AD, one-stage mesophilic system. Some examples of AD with MBT being practiced in European Countries are shown in the following table:

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[23] (UNEP)

Table 2.8 Large scale AD using MSW mixed waste with MBT system in European Countries

Location	Plant Capacity	Start up year
Vitoria, Spain	120,000 ton/year	2006
Alicante, Spain	180,000 ton/year	2008
Leszno, Poland	50,000 ton/year	2010
Mirandela, Portugal	55,000 ton/year	2011

Source: (Organic Waste Systems, 2011)

RDF in Europe is usually part of an MBT plant where metals and inert materials are taken out from the organic fractions for composting and the rest of the fractions with high calorific value is made into RDF. RDF production form MSW in most commonly practiced in EU countries where separation and recycling is active such as Austria, Germany and Netherlands. The RDF products are mainly incinerated in fluidized bed incinerators, district-heating plants, or in paper mill boilers. Only 70% of the RDF products have secured market to be combusted, while the rest have to be stored[24].

The German sustainable waste management ordinance has three provisions, which are:

(i) Ordinance on environmentally sound disposal of municipal waste.
(ii) Ordinance on biological treatment of waste.
(iii) Ordinance to amend the wastewater ordinance.

The first provision, mentioned about the closing of outdated landfills and landfills without ceilings. It also orders to put to an end for any kind of disposal of non-treated waste. Thermal treatment and Mechanical Biological Treatment are suggested to be taken into practice.

Packaging waste is covered under the packaging directive, which produced several terms such as Extended Producer Responsibility (EPR), Deposit refund system, and Polluter Pays Principle (PPP). These systems take care of wastes such as packaging, beverage bottles, and batteries, which are collected separately for disposal or material recovery.

Based on the France case studies, waste incinerator with energy recovery could produce energy that exceeds the process requirements and results in the net export of energy. Energy can be recovered in three ways; all-electric, all-heat, and combined-and-heat power (CHP). The most commonly practiced one is CHP as it recovers more energy than the other two options. Practices in France has shown significant amount of energy recovered, only about 21% is used for sustaining the incineration plant while the rest (up to 80%) is sold to the electricity grid[25]. However, in Asian region context, incineration is not very much practiced. This may be due to the high organic material (40 to 60%), high moisture content (40 to 60%), high inert content (30 to 50%), low quantity (200 to 600 g/capita/day) and low calorific value content (800 to 1000 kcal/kg) in MSW[26].

Incineration plant requires a high calorific value. The calorific value of Indian waste is only 800 to 1000 kcal/kg, this is slightly lower than China with 1195 kcal/kg and the developed countries with 2007.6 kcal/kg to 4063 kcal/kg. The minimum calorific

[24] (European Commission, 2009)
[25] (Autret, 2007)
[26] (Sharholy, 2007)

value for an incineration plant is 1434 kcal/kg and the average of the calorific value throughout the year should be above 1673 kcal/kg[27]. To meet the required minimum calorific value, China adds 50% of coal in the boiler. China's waste generation/capita/day is 1 to 1.58kg, very close to EU countries, which is 1.37 kg/capita/day, or to OECD countries, 1.53 kg/capita/day. On the other hand, India only has 200 to 600 grams/capita/day waste generated (Mumbai produces 7000 TPD waste = 78,000 TPY).

From the energy-balance point of view, Incineration plant may look as the most energy efficient option due to its ability to recover energy. But with the above mentioned Asian region waste characteristics, incineration technology may not be the best option. Attempt of running incineration plant in Timarpur in Delhi (1988) has failed and this lead to public skepticism on the technology.

According to a study comparing RDF and Incineration, Incineration is only better in energy balance when it also have a cogeneration unit or CHP (Combined Heat and Power) where the heat from incineration plant is also used to either generate electricity or to utilize the heat for district heating system[28]. District heating is only common and reasonable to build in places where they have long winter. China temperature is between -4°C to 30°C While India is between 18°C to 45°C. And the cooler part of India is the less populated one therefore it reduce less amount of waste. Due to this fact, district heating system is less likely suitable for Indian cities, however there is potential of creating district cooling system but this needs further research and experience.

Japan

Municipal Solid waste in present Japan is mainly segregated into combustible, noncombustible, and recyclable Polyethylene (PET) bottles, paper and cardboards, and glass bottles). The collection is usually done on different days and bulky waste should be collected with additional fees. The combustible (including kitchen waste, plastic and paper based packaging) are thermally treated with incineration. The types of incineration technologies used are fluidized bed incinerator, rotary kiln incinerator, pyrolysis, and mass-burn system. In some places, composting is also done with rotary drum composting[29].

One of the holistic approaches on solid waste management initiated in Japan is the concept of Eco-Town. This concept was a national initiative inaugurated in 1997 by the ministry of health labor and welfare with two aims: to extend the life of existing landfill sites and to revitalize local industries. An eco town site allows the use of by-produces from cities as alternative raw materials or energy source in industrial operations, which is called the Urban Symbiosis[30].

One of the most significant regulations on waste is The Basic Law for Establishing a Recycling-Based Society, came in force in January 2002. It underlines the target of 2010 aims on improving resource productivity by 40%, recycling by 40%, and decrease landfill by 50% on the 2000 basis. Similar to Germany, it has law on packaging. The other specific laws on waste are for home appliances (refrigerator, television, air conditioner, etc), construction materials, food waste from manufacturers, and domestic automobile recycling law.

[27] (The World Bank, 2000)
[28] (Consonni, 2005)
[29] (Global Environment Centre Foundation, 2011)
[30] (Berkel, 2009)

There are 26 eco-towns and 61 innovative recycling activities in operation in Japan for both industrial and urban symbiosis that are receiving partial government subsidies. All combined, the capacity is about 2 million ton/year. Eco-towns are usually divided into divisions and the most common divisions are: (1) Alternative fuels and raw materials (from organics, plastics, wood, ash, slags into cement materials), (2) Construction and demolition waste (from inert waste to roads and infrastructure materials), (3) End-of-life vehicles (dismantling and recycling of automobiles, (4) Glass (reuse and recycling of glass bottles), (5) Industrial waste (recycling or incinerating industrial waste), (6) Metal recovery (material recovery from electronic goods), (7) Municipal solid waste (incineration with heat recovery for power generation or production of RDF), (8) Organics (AD for organic matters), (9) Paper (paper and cardboard recycling), (10) Plastics (recycling from plastic packaging), (11) Waste electric and electronic goods (dismantling and material recovery), (12) Wood (chipping and reuse)[31].

2.3.3 Comparison and recommendation

Table 2.9 summarizes the technical pros and cons of each technology option. The conclusion of this study is that composting has the lowest risk of failure due to the region's experience in the technology. Anaerobic digestion is the ideal energy recovery option but is not possible due to the required purely organic waste input. Landfill Gas collection is a temporary solution to recover energy from the already existing sanitary landfill. Incineration is effective in killing germs and pathogens of mixed waste. However, it consumes a lot of energy especially to treat the high moisture organic waste.

Table 2.9 Pro and contra points of solid waste technology options

	Pro	Con
Composting	Well practiced in Asia, low investment, operation, and maintenance costs	Low product quality lead to constraint in finding committed market. Mainly done in small – medium scale. Energy consuming and may cause odor problem because it is practiced in the open air.
AD	Allow optimal utilization of organic waste	Lack of experience in large scale practice and lack of CER support
Landfill Gas (LFG) Utilization	Allows energy recovery from the existing sanitary landfill.	It is only a temporary solution to the already existing landfill. Creating landfill for the sole purpose of LFG utilization should not be pursued
Incineration	Effectively kills germs and pathogens of mixed waste	Require high calorific value, high input capacity, capital, operation and maintenance intensive.

Source: ADB consultants, 2011

[31] (Berkel, 2009)

Waste segregation is the key success in implementing any kind of waste management technology to allow material and energy recovery. Only when segregation is achieved, the waste management hierarchy can be implemented. Waste segregation is done in many developed countries such as EU countries and Japan but it is also practiced in community levels in developing countries especially due to the immediate incentive from recyclable materials.

2.4 Summary

Ideally, waste should be treated according to the waste management hierarchy; prevention, minimization, reuse, recycling, energy recovery, and finally disposal. This hierarchy can be best achieved when manufacturing companies would comply on better packaging, producing more durable goods and using environmentally friendly materials as well as taking the waste back from the market for recycling. This kind of approach has become more popular in the developed countries but in the developing countries, the progress is slower than the rate of growth of the waste and the rare existence of source-separation practice means that optimal treatment in the downstream should be designed.

Table 2.10 Summary of MSWM technologies SWOT analysis

Technologies / Region		Strength	Weakness	Opportunity	Threat
Composting	Developing Asian countries	• Well practiced • Simple operation	• No usable energy recovered • Odor emissions	• Separate collection of food market waste may increase quality	• Low product quality: market loss • Operation in rainy seasons: failure
	Developed European countries	• Has been practiced since 1960's • Existing centralized facilities	• Mixed waste composting does not work except in Greece and Spain	• Source separated compost are marketable	• Product mainly regarded as soil conditione r only, not fertilizer: low price
Anaerobic Digestion (AD)	Developing Asian countries	• The high organic solid waste composition volume may be reduced up to 50%	• High specification and monitoring system • Limited to small scale	• Subsidy and Feed-in tariff possibility in the future and through CDM	• High investment cost • Falling carbon price
	Developed European countries	• Has been practiced for the last10 years • Available composters made in Belgium & France	• Effectiveness vary	• Guaranteed subsidy for renewable energy and attractive FIT	• Lowperformance by lower quality chinese made machineries may reduce trust in this technology
Landfill Gas (LFG) utilization	Developing Asian countries	• Takes mixed waste (except inerts) • Many existing landfills in the region	• An end-of-pipe technology	• May bring in CDM benefits from GHG avoidance	• Inefficient practice may lead to failure in receiving CDM

	Developed European countries	• Landfills are no longer active or supported in the region	• Is not useful after the lifetime of the landfill is over	• Is useful for the remaining landfills	• The number of landfill is declining
Incineration	Developing Asian countries	• Kills all pathogens, virus and germs especially existing in mixed waste	• Cost intensive • High specification and monitoring system	• If energy recovery is conducted, there is possibility for feed-in-tariff benefit	• High investment and operational costs
	Developed European countries	• Reduce waste volume and leachate • High calorific value waste is suitable	• Cost intensive • High specification and monitoring system	• If energy recovery is conducted, there is possibility for feed-in-tariff benefit	• High investment and operational costs but still cheaper than recycling

The physical waste characteristics in developing Asian MSWM are; waste are mixed, high in moisture, and low in calorific value. The institutional problems in developing Asian MSWM are; massive existence of scavenger, low maintenance skill, low budget, and lose emission regulation. The technical problems in conducting environmental assessment in developing Asian countries is the non-existence of higher technology in practice lack of information and inventory data.

Physical advantages in the MSWM in developed countries are the high calorific value of waste that is suitable for energy recovery by combustion. When waste is segregated it allows different kind of treatment methods to be applied efficiently. Institutional advantage in the MSWM in developed countries: energy recovery is subsidized by feed-in-tariff and other incentives. The technical advantages in MSWM in developed countries are that technology and highly skilled labor necessary to operate the high technologies are available.

Based on the SWOT analysis summarized in table 2.10, the recommendation for the developing Asian country is composting as the first step to reduce waste volume that is dominated with the bio-waste. Also based on this analysis, in the implementation of the other technology may also be adapted when waste can be segregation at source in the future.

CHAPTER III

COMPARATIVE ANALYSIS OF LCA METHODOLOGIES WITH APPLICATION TO JAKARTA MSWM

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3.1 Introduction

3.1.1 Research objective and methodology

One of the important steps in Life Cycle Analysis (LCA) framework is the Life Cycle Impact Assessment (LCIA). The available methodologies have different approaches and motivations. This study compared the two widely used LCA/LCIA approaches; Eco-indicator and Eco Scarcity, with an original approach Environmental Load Point (ELP). The aims are to see how the results differ and to identify the main cause of the differences. Impact Assessment is one of the required steps within LCA framework by The ISO 14040[1]. Figure 3.1 shows the LCA frameworks. The structure of LCIA contains four phases, which are classification, characterization, normalization and weighting. The first two are obligatory, while the second two phases are optional. This paper focuses on the options of LCIA methodologies available and discusses the weighting approaches that could be conducted to further supervise the results. For better understanding on how the available options differ, an application of the available methods was conducted to a scenario of Municipal Solid Waste Management (MSWM) in Indonesia.

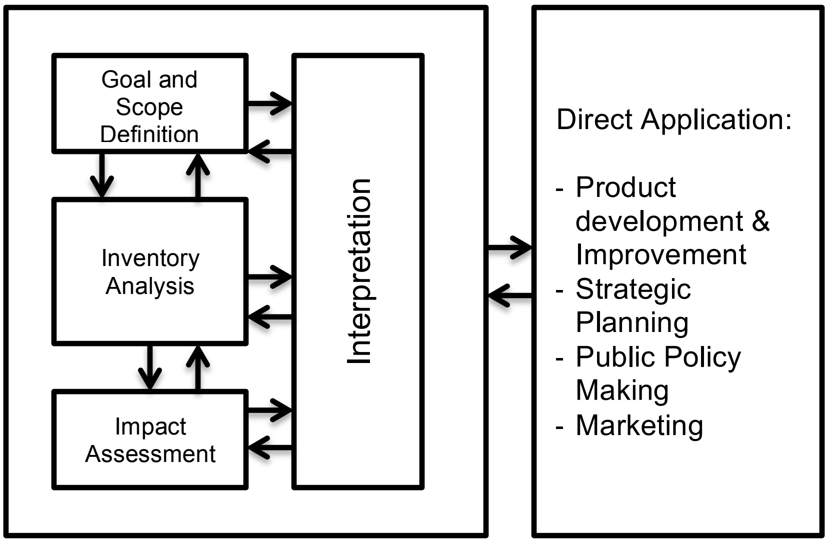

Figure 3.1 LCA Framework based on ISO 14040 standard

There is a number of LCIA models that can be grouped into three groups, which are The mid point (also known as impact categories) approach methodologies, The end Point (also known as damage categories) approach methodologies and The combined mid point and end point approach methodologies. The methodologies that fall to the first group are CML[2], EDIP[3], 1997 and TRACI[4]. The methodologies that fall in the second category are including Eco-Indicator 99[5], Environmental Priority Strategies (EPS)[6], and Eco Scarcity[7]. T (DTU Management Engineering)he methodologies that

[1] (International Organization for Standardization (ISO), 2006)
[2] (Institute of environmental Sciences (CML))
[3] (DTU Management Engineering)
[4] (United States Environmental Protection Agency, 2012)
[5] (Goedkoop & Spiensma, 2001)
[6] (Steen, 1999)

fall in the third category are ReCiPe 2008[8], LIME[9], and Impact 2002+[10]. The selected Models in this study are Eco-Indicator 99, Eco Scarcity and ELP[11][12][13][14][15]. These methodologies are chosen due to the inclusion of waste disposal especially landfilling in as one of the impact categories. This study is important to show how different methodologies affect the LCA results and to identify the advantages and disadvantages of the applications in a developing country case study in particular.
This study identified the differences of the selected methodologies by reviewing the published methodology reports, applied them on a scenario of an Indonesian MSWM to see how the result differs.

3.2 Past LCA methods comparative studies

There have been several studies dedicated to comparing the available LCA and LCIA methodologies. Table 3.1 listed some of them, the insitution who did the study, the methodology compared and the main discussion and result of each of the study. The study done by Chalmers University in sweden focused on the weighting process of an LCA. The study claims that the weighting step should be seen as a test of compatibility between the environmental impact profiles and the other profiles rather than a procedure to come up with a true measure of an aggregated impact. This study is important as to identify, what is the role of weighting in an LCA especially within the ecoscarcity, EDIP, Ecoindicator and EPS methodologies. Another interesting study was done by Ecole Polytechnique de Montreal. This Canadian study stated that combination of panel approach, criteria judgments, distance-to-target and Multi-Criteria-Decision Aid to develop weighting factors is a valid approach and recommended.

Table 3.1 Previous studies on LCA methodology comparison

Title of Journal Article	Institution, location	Methodology	Main Discussion
Weighting in LCA – Approaches and Applications	Chalmers University of Technology, SWEDEN	Ecoscarcity 97, EDIP, Ecoindicator 99, EPS 2000	Weighting step should be seen as a test of the compatibility between environmental impact profiles and different value profiles rather than as a procedure leading to a true measure of the aggregated impact.
LCA Methodology: Weighting in LCA in a Global Context	Ford Research Laboratory, GERMANY and USA	Mentions of nagata methods, eco-indicator, Yasui method	Weighting is not globally agreed due to subjectivity and local environmental imperatives thus it should be done separately from technical LCA study, reflect values and visions of the organization and targeted market in qualitative way

[7] (Frischknecht, Steiner, & Jungbluth, 2009)
[8] (Goedkoop, Heijungs, Hujibregts, Schyver, Struijs, & Zelm, 2012)
[9] (Itsubo & Inaba, 2003)
[10] (Jolliet, et al., 2003)
[11] (Nagata, 1996)
[12] (Shimizu, 2010)
[13] (Onoda, 2010)
[14] (Hu, Onoda, & Nagata, 2011)
[15] (Pandyaswargo, Onoda, & Nagata)

LCA in Japan: Policy and Progress	Swiss Federal Institute of Technology and University of Tokyo, SWITZERLAND and JAPAN	Comparing EPS, EcoPoint, Eco-Indicator95, Nagata	Sweden's EPS system is based on a willing-ness to pay, while the EcoPoint represents the environmen- tal capacity of Switzerland. The Dutch EcoIndicator "95 is based on the European ecosystem. In contrast, the methods of NAGATA and YASUI define all consumption and emissions on a global scale, where the world is assumed to be equal to a region
On the Meaning of the Distance-to-Target Weighting Method and Normalization in LCIA	Finnish Environment Institute, FINLAND	"Distance-to-Target weighting" method – Multiattribute Value Theory (MAVT)	Electre-type and AHP are claimed to be not able to offer widely accepted foundation for value measurement of weight. MAVT can provide which aggregation rule is required, what the concept of weight mean and how it can be assessed.
Development of weighting factors in the context of LCIA	Ecole Polytechnique de Montreal, CANADA	Panel approach and Multi-Criteria Decision Aid (MCDA)	MCDA can establish frameworks and judgment boundaries. MCDA is a combination of panel approach, criteria judgments, distance-to-target and MCD

Source: compiled by author

3.3 Overview of the compared LCA methodologies

3.3.1 ELP

The ELP methodology was developed in 1996 in Nagata Laboratory of Waseda University presented in the Japan Society of Mechanical Engineering. The methodology has been improved throughout the year and recently has been applied outside Japan. The impact category classification in this method is divided into 9 categories, which are, energy depletion, global warming potential, ozone depletion, acid rain, resource consumption, air pollution, ocean and water pollution, waste disposal, and ecosystem influence. Furhtermore, these impact categories are grouped into 4 damages categories, which are, impact to human health, impact to future production capacity, impact to resource protection and impact to ecosystem sustainability. The characterization and normalization of this methodology is adjusted to the annual emission and consumption in the concerned country where the case study is taking place. Finally, weighting is panel based. For this purpose, Analytic Hierarchical Process (AHP) questionnaires been distributed in Indonesia.

ELP methodology provided an integrated three steps formula, where all of the LCIA steps are included throughout the LCA stages. This formula is elaborated by Equation1

$$A_j = \sum_k (C_{j,k} \times TQ_k)$$

$$ELF_k = \sum_j (C_{j,k} \times W_j / A_j)$$

$$ELP_i = \sum_k (ELF_k \times Q_{i,k})$$

Equation 1. ELP quantification formula

3.3.2 Eco Point

Eco Scarcity methodology, which is also known as the Eco Point (EP) method, was developed in Switzerland. The development started in the 1990 and the first release was in year 1997. The latest version is called Eco-Factors 2006 released in 2009 by the Swiss Federal Office for the Environment. The classification style is the endpoint approach where the categories responded to political considerations. These end point categories are, ozone depletion, photochemical oxidant formation, respiratory effects, air emissions, surface water emissions, radioactive emissions, cancer caused by radio nuclides emitted to the sea, emission to ground water, emissions to soil, landfilled municipal waste, hazardous waste (underground storage), radioactive waste, water consumption, gravel consumption, primary energy resources endocrine disruptors and biodiversity losses. The characterization and normalization is corresponding to the IPCC 2001 Global Warming Potentials (GWPs) and the weighting is responding to the two political goals, the Kyoto Protocol commitment and the memorandum to the CO2 act where 10% of CO2 reduction on the 1990 baseline should be achieved by the year 2010.

3.3.3 Eco-Indicator 99

The Eco-Indicator methodology was developed in The Netherlands in 1995 under a joint project of Pre consultants with several private manufacuring companies. The methodology has been improved and the latest version was published in 1999. For classification, the methodology has developed 11 impact categories, which are, climate change, ozone layer depletion, acidification, eutrophication, arcinogeic, respiratory effects, ionizing radiation, ecotoxicity, land use, mineral resources, and fossil resources. And 3 damage categories, which are, eco system quality, human health and natural resource. The values of characterization and normalizations were derived from resource consumption and emissions within the European region between 1990 to 1994. The panel based weighting is assigned to the 3 end points.

Table 3.2 Comparison of LCA methodologies

Technology		Methodology		
		ELP	**Eco - Indicator 99**	**Eco Point**
Developer		Waseda University, Nagata Laboratory	Pre consultants, Philips consumer electronics, NedCar, Oce Copiers, Schuurink, CML Leiden, TU-Delft, IVAM-ER, CE Delft	Swiss Federal Office for the Environment
Classification categories	Mid-points	9	12	-
Classification categories	End-points	4	3	16
Characterization and Normalization scope		Japan - Worldwide	The Netherlands – Europe (Normalization to end-points only)	Switzerland - Worldwide
Characterization methodology		Panel survey	Environmental interventions impacts from European production between 1990 to 1994	Characterization and Normalization are performed with the overall flow of greenhouse gases calculated using the current GWPs (IPCC 2001)
Weighting approach		Panel survey	Panel based	Responding to the 2 political targets: kyoto protocol and the memorandum to the CO_2 Act
Unit		Environmental Load Point (ELP)	Eco Indicator Point	Eco Point (EP)

3.4 Indonesian waste scenario

The Indonesian MSWM scenario selected for application of the three LCIA methodologies is located in Bekasi city, receiving 6000 tonne/day of mixed MSW from Jakarta area. Figure 3.2 shows the composition of the waste.

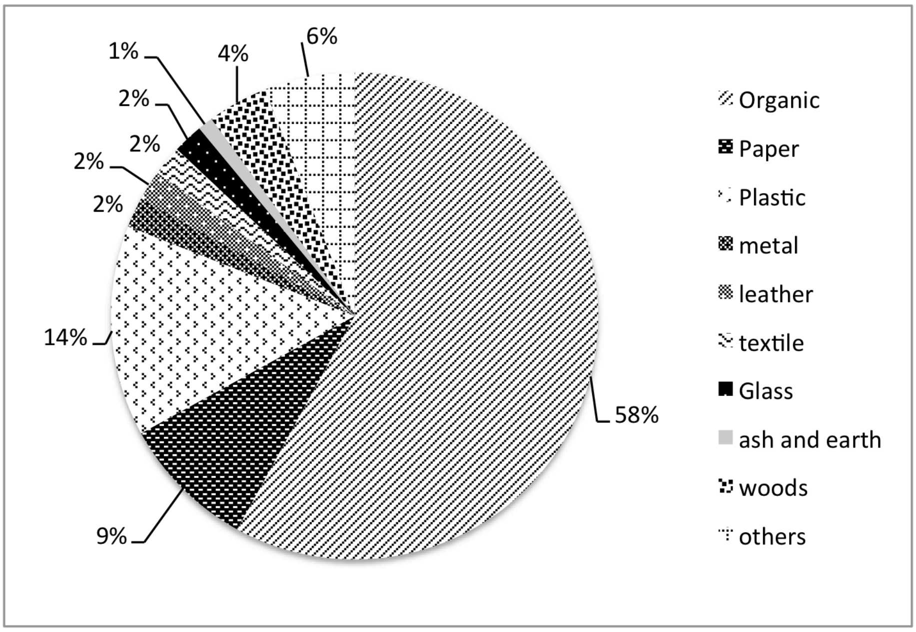

Figure 3.2 Composition of Jakarta Municipal Solid Waste

For the two constructed scenarios, a complete waste segregation of the collected mixed waste is assumed. In Scenario 1 (Figure 3.3), the organic waste is composted, the rest of the waste are landfilled with landfill gas collection and energy recovery. In scenario 2 (Figure 3.4), the organic waste is anaerobically digested, the rest of the waste are landfilled with landfill gas collection and energy recovery. Processes in Figure 3.3 and 3.4, are the processes involved in the scenario. Processes in Figure 3.5 are the processes replaced by the scenario 1 and 2 to provide the same amount of fertilizer and electricity. The inventory data used is from ecoinvent database and the selected indicators are CO2, CH4, NOx, SO2, and waste disposal.

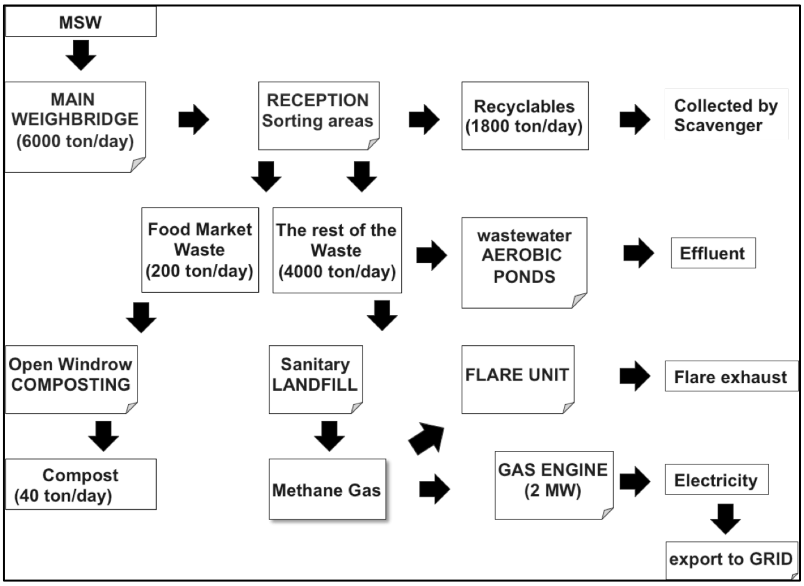

Figure 3.3 Scenario 1 of Jakarta MSWM case study

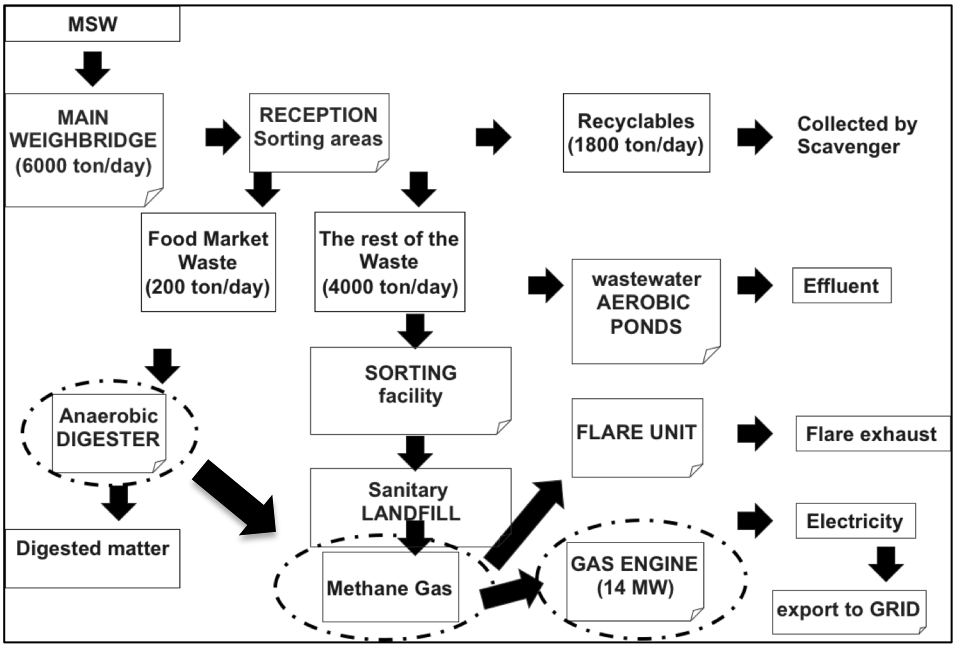

Figure 3.4 Scenario 2 of Jakarta MSWM case study

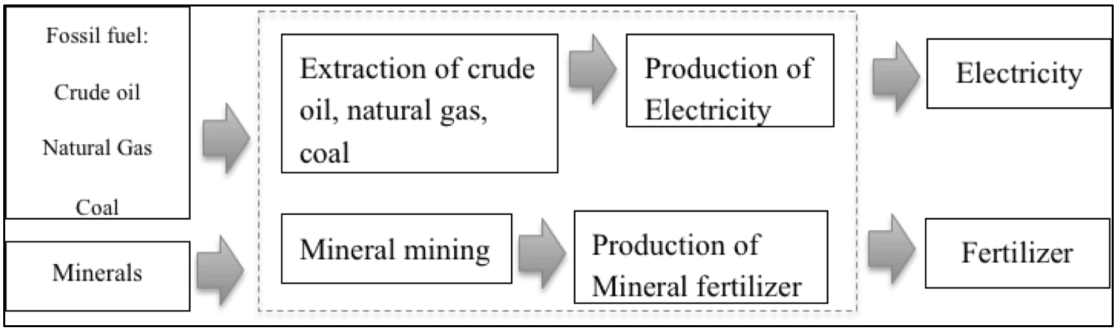

Figure 3.5 Electricity and Fertilizer Production in Indonesia in business as usual

3.5 Results and Discussion

The impact assessment for the described case studies were conducted using the three selected methodologies; Eco-Indicator 99, EP, and ELP. The results are summarized in table 3.3. The results of CO2 and CH4 indicator show that scenario 2 is by far the better option according to all methodologies' results. Biogas in the scenario 2 is well captured within the anaerobic digestion process and landfill gas recovery. The result of NOx and SO2 indicator also show that scenario 2 is the better option according to all methodologies' results. Mainly because, the pollutant emitted from the coal power plant is avoided by the energy recovery of both scenarios. The result of waste disposal indicator also show that scenario 2 is the better option according to all methodologies' results. More waste going to the landfill is avoided in the Anaerobic Digestion process as compared to composting process. Total result show better performance in scenario 2 due to avoidance of fossil based energy generation and the avoidance of mineral mining and the production of mineral fertilizer. Eco-indicator and ELP give weight as 0 and 1 unit respectively for waste disposal. On the other hand, EP puts weight of 500 units for solid waste. The difference becomes only apparent in the case of Eco Indicator, because it gives 0 values for waste disposal category.

Table 3.3 LCA results from the selected methodologies

Indicators	Scenarios					
	Scenario 1 (LFG + composting)			Scenario 2 (LFG + anaerobic digestion)		
	Methodology					
	ELP	Eco Point	Eco-Indicator	ELP	Eco Point	Eco-Indicator
CO_2	-3.67E+08	-4.63E+07	-2.24E+08	-3.77E+08	-3.71E+08	-3.79E+08
CH_4	8.23E+05	4.19E+05	1.99E+06	5.34E+05	2.27E+05	7.00E+05
NO_x	-2.50E+07	-4.53E+07	-2.32E+07	-8.27E+07	-8.59E+07	-8.24E+07
SO_2	-1.10E+08	-1.81E+08	-1.45E+08	-1.81E+08	-1.82E+08	-1.82E+08
Waste disposal	1.18E+08	3.78E+08	0.00E+00	1.72E+08	8.04E+04	0.00E+00
Total Load avoided	-3.41E+08	-1.87E+07	-3.90E+08	-4.68E+08	-4.67E+08	-6.42E+08

3.5.1 Financial projection for anaerobic digestion plant implementation in Jakarta

In the scenario where biogas plant establishment in the disposal site of Bantar Gebang landfill is replacing the composting plant, the following assumption can be taken into account; revenues are expected to be coming from the sale of electricity, fertilizer, CERs, tipping fee and heat. The assumed electricity price is 0.14 USD/kWh, which is the feed-in-tariff of electricity generated from biomass in Indonesia. The heat is assumed to be self-consumed and valued a quarter of the electricity price. The fertilizer price is assumed to be similar with the price of selling compost fertilizer from the composting plant, which is 79.50 USD/ton. There are two kinds of fertilizer from the by-product of a biogas plant; liquid and solid. The liquid fertilizer is also assumed to have a similar price. The initial investment for a 200 TPD organic waste input capacity approximately 102 million USD. Assuming interest rate of 7% and inflation rate of 8%. Assuming the optimistic 10 USD/ton CO2-eq and tipping fee of 8.9 USD, CER income guaranteed throughout the 25 years project, even with a negative NPV, the payback period is predicted to be 7 to 13 years. However, the actual trend of carbon credit price has been decreasing gradually. When carbon credit price is decreasing or when the project is assumed to have no CER income, an anaerobic digestion project financial performance would be very hard to compete in the market. A payback time is hardly possible to be achieved.

Table 3.4 Assumption of AD implementation financial projection

Input profile		Unit	Finance		Unit
Organic waste (OW)	2,520	TPD	Capital	8.1million	USD
Biogas (BG)	100	M3/ton.OW	Interest rate	7	%
CH4	55	%.biogas	Loan payback	15	Years
Heating value	6	kWh/m3.CH4	Depreciation	25	Years
			Income increase		
			Disposal fee		

			Electricity Heat Fertilizer CDM **Cost increase** Inflation (op.&mntc.) CER monitoring	0 2 2 0 0 12 0	% % % % % % %
Benefit		**Unit**	**Cost**		**Unit**
Disposal (tipping) fee Fertilizer price Electricity FIT price Heat FIT price CER	8.9 79.50 0.14 0.04 10	USD USD/ton USD/kWh USD/kWh USD/ton CO2-eq	Depreciation Capital payback Loan interest CER approval CER monitoring Insurance Operation Maintenance	25 15 7 200,000 30,000 1 6 6	Years Years % USD USD %.investment %.investment %.investment
Utilization		**Unit**	**Fertilizer**		**Unit**
Electricity production Heat Losses Self-electricity Self-heat Working hours	40 50 10 20 50 8000	% % % % % hours/year	Water content Price mineral	60 79.5 10	%.OW USD/ton %.solid

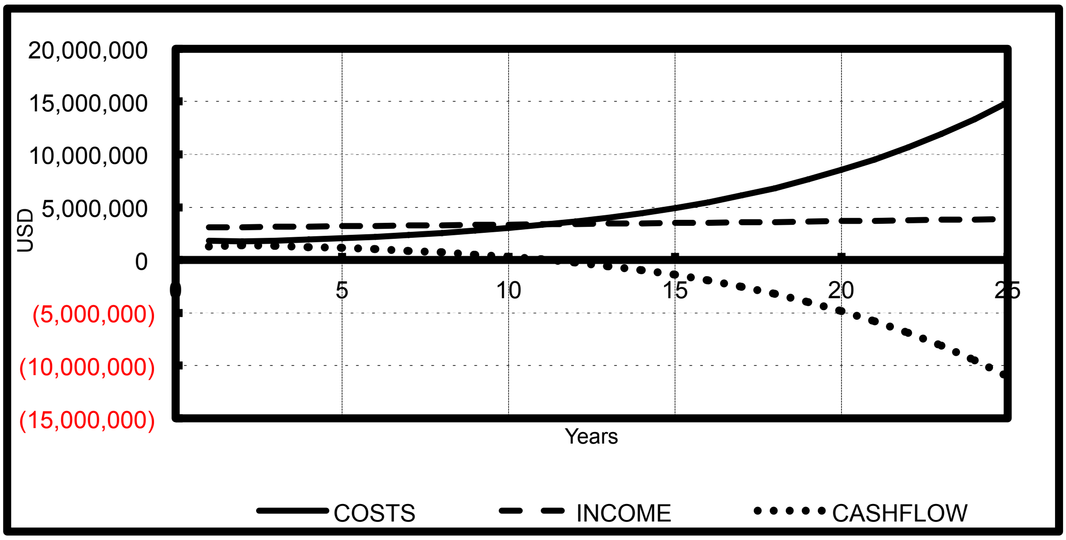

Figure 3.6 Cost, income, and cash flow projection

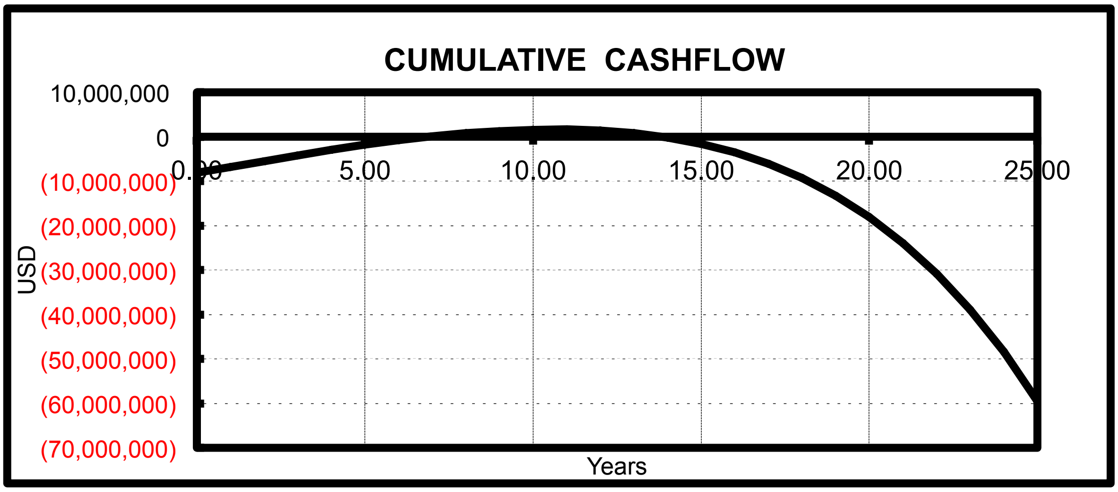

Figure 3.7 Payback period projection

3.5.2 SWOT analysis for Anaerobic digestion technology implementation in Indonesia

A SWOT analysis of AD implementation in the developing Asian countries is provided below.
The strength of AD under the condition of having source separated waste or under the MBT mechanism or with community based approach are:

(i) AD may suffice communities need of locally produced energy
(ii) High content of moisture and organic content are optimally utilize for energy recovery
(iii) Climate and temperature of Asian region is optimal for running an AD plant efficiently without additional energy consumption for heating
(iv) Culturally, the Hindu-majority region creates suitable type of high amount of organic waste, and people's ease at handling cow manure.
(v) In the MBT mechanism, when pre-sorting is manually done, scavengers that are now having their role of material recovery by collecting recyclable materials may be employed and equipped with proper knowledge and tools of handling mixed waste therefore threats from NGO and scavenger union may be avoided.

The weaknesses are:

(i) The success stories and experiences is only well known for the smaller scale of AD where waste is source segregated such as the kitchen waste and cattle dung. Utilizing MSW mixed waste in large scale requires high investment and maintenance on presorting technology.
(ii) Manually handling waste is prohibited by India SWM Rules 2000 (Schedule II) unless with proper precaution under unavoidable situation.

The opportunities are:

(i) The source segregation enforcement
(ii) The application of MBT or the community based approach

The threats are:

(i) Unlike the small scale ones, large scale AD does not seem to be popular as CDM project. If this continues, it will be very discouraging since Certified Emission Reductions (CER) income is significant in the sustainability of AD project.

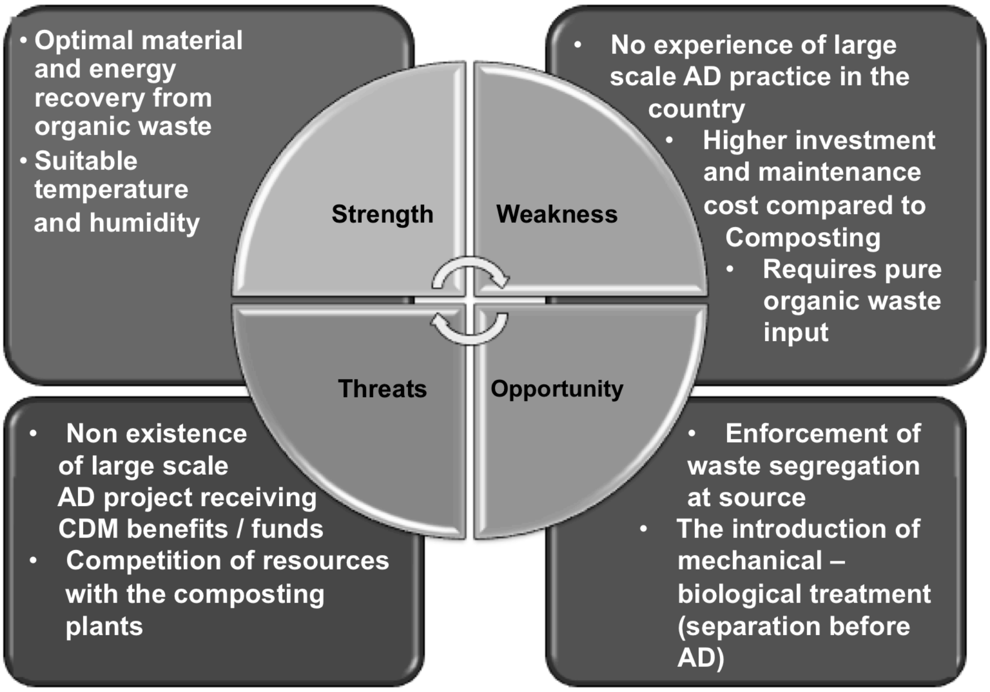

Figure 3.8 SWOT analysis of Anaerobic Digestion technology implementation in Indonesia

3.6 Summary

There are ranges of selections of the available LCA methodologies varying in their scope and approaches. Eco-indicator, EP and ELP methodologies were selected in this study for comparison because all of them comply the first two phases; classification and characterization. The last two phases of LCIA; normalization and weighting are optional but complied by the three methods with different approaches. The analysis showed that Eco-indicator and ELP are more similar to each other both in their approaches and coefficient values. The end results provided by the three methodologies shows slightly different values, but all of them provide the same conclusion that AD is more environmentally friendly than composting. The SWOT analysis of AD implementation in Asian Developing countries shows that it may not be done in the near future mainly due to the mixed waste, therefore, further analysis is required and to be conducted in the next chapter.

CHAPTER IV

ELP APPLICATION IN INDONESIA, INDIA AND CHINA MSWM

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4.1 Introduction

4.1.1 Objectives and Methodology

The main objective of this study is to identify the most appropriate method to be adopted in the region by using the environmental load point (ELP) methodological approach. Furthermore, this study attempts to measure the environmental impact and energy recovery potential by applying life cycle assessment (LCA) to different scenarios of waste treatment in the three countries. The scenarios proposed are adjusted to the waste characteristics, which can be described as mixed waste with high organic composition. Composting and anaerobic digestion are proposed to favor the high organic composition, incineration is proposed to respond to the mixed state of the waste collected, and landfill gas collection for energy recovery is chosen to make use of the sanitary landfill that already exists in the region. Three developing countries in Asia - Indonesia, China, and India - are selected as the study areas to represent Asia because of their similarities in high organic waste composition and the current low levels of energy and resource potential utilization.

Both primary and secondary data were used in this study. Primary data was inventory data collected from the EcoInvent database 2010 and Japan Environmental Management Association for Industry (JEMAI). Secondary data was collected from existing literature on emissions and energy recovery potentials of treatment processes. In addition, a questionnaire survey was conducted at national universities in the selected countries. The data collected was used to weigh the results in order to get a better representation of geographic, social, and political interests in the country[1].

In the year 2002, a thorough guideline of LCA application in municipal solid waste (MSW) was prepared by Nordtest Finland[2]. This guideline, along with ISO14040[3], ISO 14044[4], and an LCA methodology study by Finnveden, G.[5], has significant contributions in applying ELP methodology in this study. The ELP methodology is an Excel-based LCA tool that allows for a high degree of adjustability and transparency as well as social factor integration to refine and personalize results. This methodology has been used to assess municipal incinerators and water supply plants as well as product manufacturing factories in Japan[6]. The study done by Onoda analyzed six options for municipal waste management in Kitakyushu City. The business of usual incineration + ash landfilling was compared to five other scenarios elaborated in Table 4.1 The result showed that the scenario where the non-organic waste is incinerated and organic waste is digested anaerobically has the lowest Environmental Load Point, highest energy recovery, and lowest CO2 emission.

The three equations involved in ELP quantification are elaborated in equation 1, equation 2 and equation 3.

---

1 (Pandyaswargo, Onoda, & Nagata, 2012)
2 (Bjarnadottir, Frioriksson, Johnsen, & Sletsen, 2003)
3 (International Organization for Standardization (ISO), 2006)
4 (ISO, 2006b)
5 (Finnveden, 1999)
6 (Hu, Onoda, & Nagata, 2011) (Shimizu, 2010) (Pandyaswargo, Onoda, & Nagata, 2012) (Onoda, 2010) (Nagata, 1996)

$$A_j = \sum_k (C_{j,k} \times TQ_k) \quad (1)$$

$$ELF_k = \sum_j (C_{j,k} \times W_j / A_j) \quad (2)$$

$$ELP_i = \sum_k (ELF_k \times Q_{i,k}) \quad (3)$$

Table 4.1 Previous ELP study result on Kitakyushu municipal waste management scenarios

Case	Scenario	ELP	Energy recovery	CO_2 emission
1	Incineration (electric) + ash landfilling	100	100	100
2	Incineration (electric) + ash melting + ash landfilling	93	100	102
3	Incineration + ash melting + metal recycling	92	100	102
4	Direct melting (gas) + ash landfilling	98	95	103
5	Direct melting (gas) + metal recycling	96	95	104
6	Incineration (electric) + organic waste anaerobic digestion	91	125	99

Since the processes are similar, the figures were adjusted relative to business as usual (case 1) as baseline unit (100). Source: (Onoda, 2010)

4.2 Inventory data analysis

Inventory data for the processes involved in the study were taken from the EcoInvent database 2010[7], the JEMAI, and from literature that examined the existing local processes.

4.2.1 MSWM technology emission inventory

MSW treatment technologies

MSW may be treated thermally or biologically. Thermal treatment includes incineration, pyrolysis, and gasification, while biological treatment includes anaerobic digestion and composting. Thermal treatment requires high calorific value. Therefore, dry combustible waste such as plastic, rubber, and paper are desirable for this treatment. Biological treatment requires high organic content. Therefore, food waste and garden waste are desirable for this treatment methodology[8]. In this study, the technologies adopted in the scenario constructed are (1) sanitary landfill, (2) incineration, (3) composting, and (4) anaerobic digestion.

Sanitary landfill

Landfill is still the common practice of MSWM in the developing world. Sanitary landfills, although quite limited in number, exist especially in larger cities. A sanitary landfill has a proper leachate capture system and liners to prevent contamination of

[7] (Swiss Centre for Life Cycle Inventories, 2010)
[8] (Wirawat & Gheewala, 2007)

the groundwater. Although landfill is a less preferable solution, especially for non-inert waste, due to the limited lifetime (30 to 50 years) and slow biodegradation process for organic waste[9], sanitary landfill is selected in this study as an option because of the possibility of landfill gas collection for energy recovery. Sanitary landfill inventory data used in this study include landfill gas incineration and landfill leachate treatment in the wastewater treatment plant (WWTP) as well as the WWTP sludge disposal in the municipal incinerator.

Incineration

Incineration is perceived as a costly solution for MSWM due to its operational energy requirements and the flue gas treatment. It is also technically feasible only for a relatively high calorific value of 1,433 kcal[10], which is often quite high for developing Asian countries' waste to meet. For example, the calorific value of Indian waste is only 700 to 1,000 kcal[11]. However, modern incinerators have improved with efficient combustors and flue gas treatments[12]. Moreover, some plants add auxiliary fuels like crop waste and/or tires to improve the calorific value. Significant amounts of methane gas released into the atmosphere are not achieved with this technique, especially when compared to the landfilling option. The inventory data used in this study for incineration include the landfilling of the residual materials, such as the fly ash and the scrubber sludge. The energy recovery potential per kilogram of waste incinerated is elaborated in Table 4.2

Table 4.2 Electricity generated from waste incineration energy recovery

Type of waste	Net electricity produced per kilogram of waste treated (kWh/kg)
Biowaste	0.04
Paper	0.36
Plastic	0.96
Glass	0
Wood	0.36
Textiles	0.37
Others (20% water content)	0.28

Composting

Composting organic biodegradable waste takes a significant amount out of the waste stream going to incineration and landfill. This implies less landfill gas and leachate production. The bigger-scale composting plants in developing Asian countries often use open windrow composting. This aerobic composting approach typically takes about 4 to 6 weeks to reach the stabilized end-product stage. The composting process in this study incorporates emissions both from the energy demand for plant operation and infrastructure. The assumed water content is 50% by weight[13]. The assumed replaced mineral fertilizer is potassium nitrate (KNO_3), as N. This mineral fertilizer

[9] (Williams, P. T. , 2005)
[10] (The World Bank, 1999)
[11] (Zhu, 2009)
[12] (Williams, P. T. , 2005)
[13] (Wirawat & Gheewala, 2007)

has N content of 14%, while that of the municipal waste compost fertilizer ranges from 10% to 22%[14]. The release of N from mineral fertilizer is, however, quite significant in the first year (up to 80%) and low in the following years, while municipal waste compost fertilizer releases N gradually throughout the years (about 10% per year)[15]. Therefore, the amount of replaced mineral fertilizer is assumed to be equal.

Anaerobic digestion

Anaerobic digestion is by far more efficient when compared to collecting landfill gas as the waste is processed in a closed container with conditioned temperature and the absence of oxygen creates the optimal environment for biogas generation. A study shows that a ton of waste in a controlled anaerobic digestion produces two to four times more methane in 3 weeks than a ton of waste in a landfill would produce in 6 to 7 years[16]. The input of anaerobic digestion should contain relatively pure organic material, the output being biogas with 55% to 60% CH_4 and 40% to 45% CO_2 that can be burned in a gas engine to generate electricity, and the residue being in the form of digested matters which can be used as soil conditioner. While biogas contains both CH_4 and CO_2, only CH_4 is considered to be convertible to electricity. Additionally, the heat value assumed in this study is 6 kWh/m^3 CH_4[17]. The assumed digested matter usable as soil conditioner (fertilizer) in this study is 40% of the organic matter input. Spreading the product fertilizer from this process might take more energy when compared to mineral fertilizer because the nutrient content is less; thus, a larger amount is required. For this reason, the emission from the spreading activity is included.

4.2.2 Electricity grid emission

The substituted electricity uses the national electricity grid thermal fuel mix. For example, in Indonesia, the fuel mix for JAMALI (Java, Madura, Bali) is used. This grid that provides 78% of the national electricity consumption[18] utilizes 53.7% natural gas, 18.74% coal, and 27.69% oil[19]. For China, the consumption of coal, oil, and gas of a thermal power plant is 96.62%, 1.87%, and 1.51%, respectively[20]. For India, the coal-based thermal power plant air emission[21] and the fuel mix of the thermal power plant, which is 82% coal, 17% gas, and 1% diesel[22], were used.

4.3 Constructed scenarios

The three scenarios constructed for the MSW treatment are a mix of incineration, sanitary landfilling, composting, and anaerobic digestion. In scenario 1, the entire amount of the mixed municipal waste is incinerated. In scenario 2, the organic waste is composted whereas the rest of the waste is landfilled in the sanitary landfill. The CO2 and CH4 (biogas) from the sanitary landfill are collected for energy recovery

[14] (Hargreaves, 2008)
[15] (Bjarnadottir, Frioriksson, Johnsen, & Sletsen, 2003)
[16] (Ahsan, 1999)
[17] (Bjarnadottir, Frioriksson, Johnsen, & Sletsen, 2003)
[18] (Tanoto, Y and Wijaya, M.E., 2011)
[19] (Gunamartha & Sarto, 2012)
[20] (Xianghua, D. Nie, Z. Yuan, B and Zuo, T., 2007)
[21] (Chakraborty, N. et al., 2008)
[22] (PSI Media Inc., 2011)

with a cogeneration unit. In scenario 3, the organic waste is digested anaerobically, and the rest of the waste is to be landfilled in the sanitary landfill, with the biogas emitted being collected for energy recovery. The desired output of the first scenario is electricity and heat. The desired output of the second scenario is electricity and compost fertilizer. The desired output of the third scenario is digested matter, which can be used as soil conditioner, and biogas to generate electricity. To estimate the emission avoided from fossil fuel-based electricity, the mining and electricity production from coal, natural gas, hydropower, and crude oil are accounted. Table 4.1 summarizes the scenarios and the desired output. The system boundary of each scenario is elaborated in Figures 4.1, 4.2, and 4.3. The summary of scenario and output are presented in table 4.3.

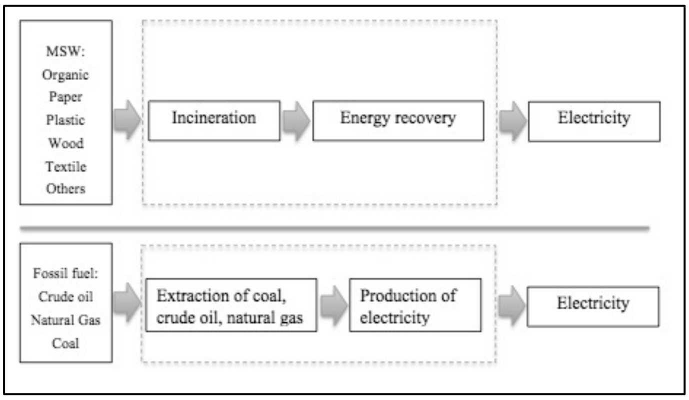

Figure 4.1 Scenario 1

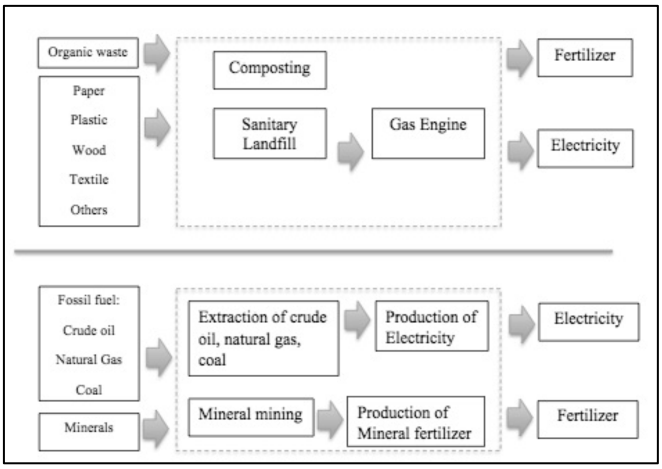

Figure 4.2 Scenario 2

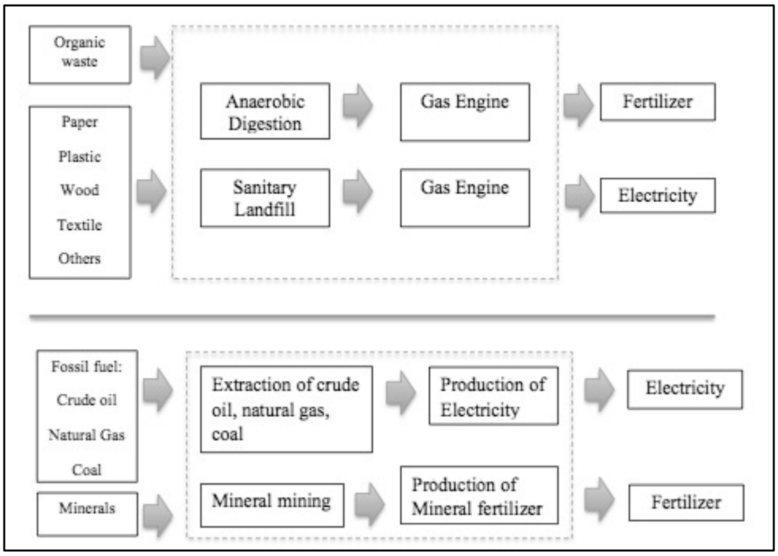

Figure 4.3 Scenario 3

Table 4.3 Summary of scenario and output

Case	Scenario	Desirable output
1	Incineration + energy recovery	Electricity
2	Composting + sanitary landfilling + landfill gas collection for energy recovery	Fertilizer, electricity
3	Biogas + sanitary landfilling + landfill gas collection for energy recovery	Digested matter, electricity

4.4 Results and discussion

The result of the first equation (*A*) is summarized in Table 4.4. The TQ value required for this calculation was collected from the government and institutions that provide the national annual consumption and emission of the related country, such as the US Energy Administration for the energy consumption[23], the Indonesian Ministry of Environment for the greenhouse gas (GHG) emission of Indonesia[24], and the United Nations Statistics[25], a study of air pollution in Asia[26], mining product consumption information from the National Statistics Office[27], China Mining Association[28], and index mundi[29].

[23] (US Energy Environment Administration, 2012)
[24] (Ministry of Environment, Indonesia, 2009)
[25] (United Nations, 2012)
[26] (Zhang, 2006)
[27] (National Statistics Office, Indonesia, 2012)
[28] (China Mining Association, CMA, 2012)
[29] (Index mundi, 2010)

Table 4.4 Annual load results

Impact category	India	Indonesia	China
Energy depletion	6.46E+10	1.49E+12	2.58E+12
Global warming	1.86E+13	1.00E+11	1.21E+14
Acid rain	9.00E+09	1.80E+09	4.56E+10
Resource consumption	2.46E+11	1.80E+09	1.62E+11
Air pollution	2.10E+10	2.10E+10	1.00E+11
Waste disposal	4.20E+10	4.20E+10	1.80E+09

To get the *W* value for the second step of the calculation using the ELP formula, AHP questionnaires were distributed. Respondents are randomly selected from faculties in top universities in the related countries, such as the Institute of Technology Bandung, Indonesia, University of Delhi, India, and Beijing University, China. University students were selected as group of respondents for the ease of regular updating and comparability across countries. Figure 4.4 shows the questionnaire results. In the questionnaire, respondents were asked to compare and rate which of the nine ELP impact categories deserve the priority of concern in their countries and which deserve less. According to the total 300 university students surveyed in the three countries, energy depletion comes in the first rank of the most important impact category in Indonesia and China, while global warming is the most important issue in India. On the second rank is global warming in Indonesia, resource consumption in China, and ozone depletion in India.

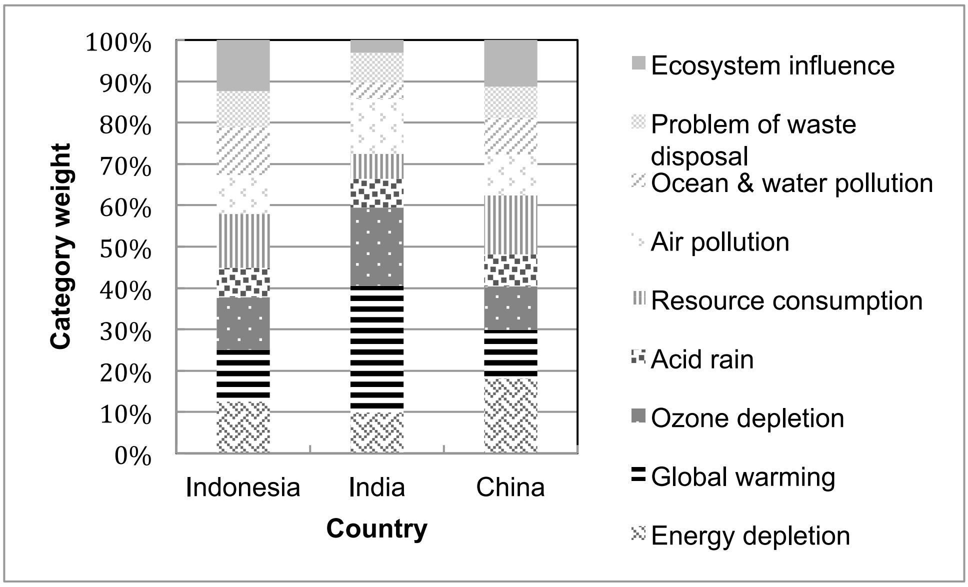

Figure 4.4 Weighting values from the AHP questionnaire

Table 4.5 summarizes the ELF result. ELF is the value of ELP per kilogram emission or resources emitted or consumed in a process. Figure 4.5 summarizes the total of ELP quantification results of the three scenarios constructed in each country. The description of the results is described country-wise for each impact category, followed with a logical discussion in order to support the results.

Table 4.5 ELF results

Impact category	India	Indonesia	China
Energy depletion	6.93E+02	8.89E+02	1.27E+03
Global warming	4.06E+02	4.06E+02	4.06E+02
Acid rain	3.28E+04	3.28E+04	3.28E+04
Resource consumption	2.01E+04	2.01E+04	2.01E+04
Air pollution	5.08E+04	5.08E+04	5.08E+04
Waste disposal	4.27E+02	4.27E+02	4.27E+02

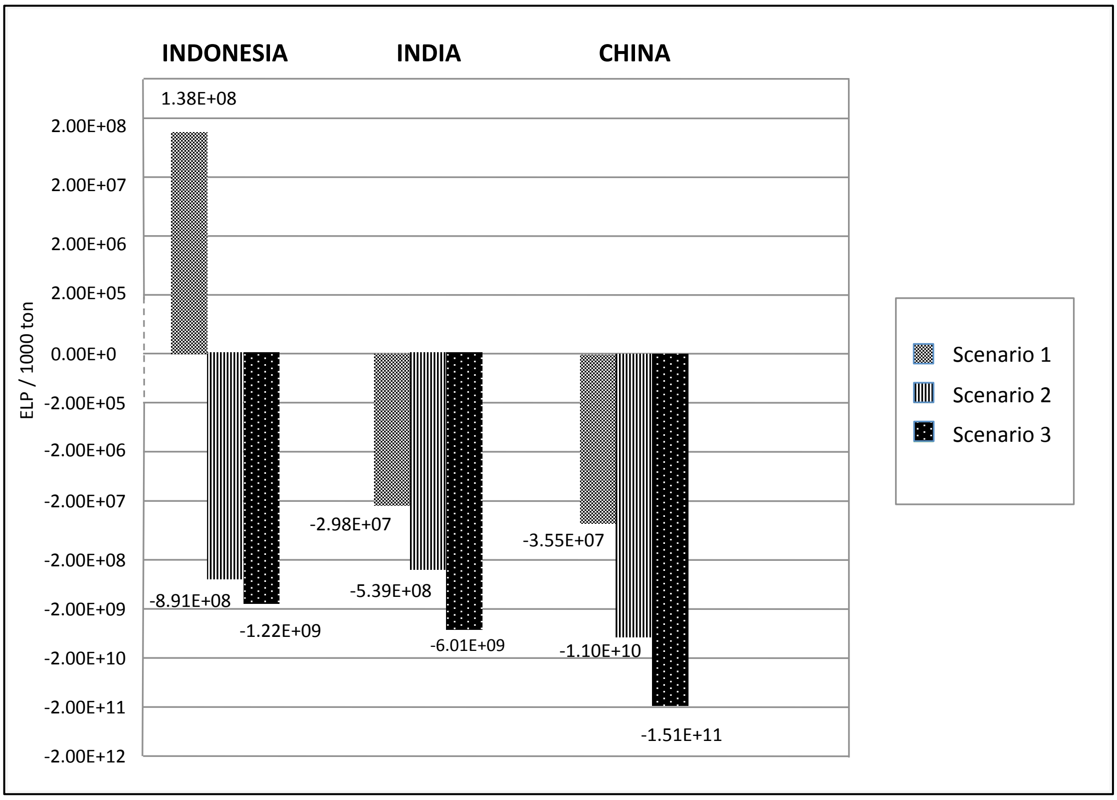

Figure 4.5 Total ELP of scenarios 1,2, and 3 in India, Indonesia, and China

The major findings extracted through our analysis are following:

All countries prefers scenario 3 as the best option. Scenario three is the one, which includes anaerobic digestion. Anaerobic digestion mainly releases energy instead of consuming energy because the microorganisms in the closed facility do the biological reaction releasing CH4. Therefore, the amount of recovered energy is high. Moreover, the by-product of anaerobic digestion is the solid and liquid fertilizer that is useful for soil conditioner and rich in nutrition for plant growth. The second best option is the scenario 2. Scenario two is the one, which includes composting. Similar to anaerobic digestion, composting is a biological treatment. However, instead of releasing energy, composting consumes energy. The bigger capacity composting plant requires excavators for turning compost pile. Moreover, it is done in the open air due to its necessity to have access to oxygen. The weakest option is scenario 1. Scenario one is the one, which includes incineration. All of the three countries have significantly high percentage of organic waste. Organic waste is high in water content. It requires a lot of energy to burn a high moisture waste; therefore incineration has the weakest performance in the analysis.

4.4.1 Indonesia

The environmental load of the ‘energy depletion’ impact category in the Indonesian case study is lowest in scenario 3, mainly due to the avoided energy to produce the mineral fertilizer replaced by the digested matter from anaerobic digestion. The ‘global warming potential’ impact category, whose indicators are CH_4 and CO_2, is lowest in scenario 3, mainly because of the closed tank of anaerobic digestion preventing gas release into the atmosphere and enabling its conversion into electricity. The ‘acid rain’ impact category is lowest in scenarios 2 and 3, mainly because of the emission avoided from the production of replaced mineral fertilizer. Similarly, the lowest environmental load for the ‘resource consumption’ impact category also lies in scenarios 2 and 3 because of the resources saved from the replaced mineral fertilizer production. The ‘air pollution’ impact category is highest in scenario 1 and lowest in scenario 3, mainly because of the CO and NO_x emitted by the incineration plant. The ‘waste disposal’ impact category is highest in scenario 2 due to the amount of waste going to the landfill plus the residual waste from the composting activity.

Among the three scenarios in the Indonesian case study, scenario 3, which is anaerobic digestion for the organic waste content and landfill gas collection for energy recovery, has the least environmental load. The digested matter replacing mineral fertilizer mainly contributes this. The fertilizer produced is a co-benefit of anaerobic digestion. This means that no additional input of energy or resources is required to produce fertilizer, and all of the potential energy is captured within the closed container of the biogas plant. Moreover, the Indonesian survey results for weighting rank resource consumption as the most important impact category. The estimated electricity recovered from anaerobic digestion in the Indonesian waste case study is 32.7 MWh for every 580 tonnes of organic waste treated, and the estimated electricity recovered from landfill gas collection is 57.7 MWh for every 370 tonnes of non-inert, non-biowaste dumped in the sanitary landfill. The estimated amount of digested matter for soil conditioner is 232 tonnes for every 580 tonnes of organic waste treated in the anaerobic digestion plant.

In practice, the technology of large-scale municipal waste aerobic digestion is not popular in Indonesia[30]. This technology is commonly applied to animal slurry or agricultural waste because of the pure organic waste content. However, countries like the Netherlands, Sweden, and Switzerland have fully developed anaerobic digestion plants for handling municipal waste[31].

4.4.2 India

The environmental load of the ‘energy depletion’ impact category in the Indian case study is lowest in scenario 1, second lowest in scenario 3, and highest in scenario 2. This is because electricity replaced by energy recovered in the incineration plant significantly reduced the consumption of coal and natural gas in the fossil-based fuel thermal power plant. The ‘global warming potential’ impact category is lowest in

[30] (Ministry of Environment, Indonesia, 2009)
[31] (Wirawat & Gheewala, 2007)

scenarios 2 and 3. This is mainly due to the biological processes in these scenarios which take out CH_4 from the global warming potential, as well as the subsequent conversion of this gas into electricity. The 'acid rain' impact category, which consists of NO_x and SO_2 as indicators, has the lowest impact in scenario 2, second lowest in scenario 3, and highest in scenario 1. The biggest contribution is from the avoided NO_x emission from the production of mineral fertilizer. The 'resource consumption' impact category, which has Fe, Ni, Sn, Al_2O_3, Au, and Ag as indicators, has the lowest environmental load in scenario 3, followed by scenarios 2 and 1, as the amount of fertilizer produced by anaerobic digestion replaces the production of mineral fertilizer. The 'air pollution' impact category has the lowest environmental load in scenario 1, followed by scenarios 2 and 3, especially because of the NO_x emission from the biogas and landfill gas cogeneration units. The 'waste disposal' impact category is highest in scenario 1 because the amount of inert material contained in Indian municipal waste produces significant amounts of slag and residues.

One of the parameter that have contributed in the Indian ELP result is, the significant amount of coal (82%) used in the Indian electricity grid fuel mix. Moreover, the weighting from community survey by the AHP questionnaire in this study ranked global warming potential and air pollution in the top three most concerning environmental issues in India. The estimated net electricity generated from combusting 1,000 tonnes of Indian waste in the incineration plant is 208 MWh.

Incineration in Indian case study shows very weak result. India is one of the developing Asian countries that has tried to adopt incineration but failed. Incineration is not feasible for Indian waste due to its low calorific value. The refuse-derived fuel (RDF) method, which increases the calorific value of waste by taking out the moisture content by gasification and pelletization before feeding it to the incineration plant, is practiced. The product of RDF is often mixed into the coal power plant[32].

4.4.3 China

The environmental load of the 'energy depletion' impact category in the Chinese case study is lowest in scenario 2, mainly due to the avoided coal and oil for mineral fertilizer production. The 'global warming' impact category is also lowest in scenario 2, mainly because of the avoided CO_2 emission from the production of the replaced mineral fertilizer. The lowest environmental load in the 'acid rain' impact category is in scenario 3 because of the avoided NO_x and SO_x emission from the replaced mineral fertilizer production. In the 'resource consumption' impact category, scenario 3 has the lowest environmental load. The biggest contribution to the load reduction is from the avoided iron and nickel consumed in the production of replaced mineral fertilizer. The impact category of 'air pollution' has the lowest environmental load in scenario 2. The $PM_{2.5}$ and NO_x emission avoided from the replaced mineral fertilizer have the biggest contribution to this result. Finally, the highest environmental load in the 'waste disposal' impact category is scenario 2 because of the higher amount of waste composted, resulting in a higher amount of residual waste from the composting activity.

[32] (IGES , 2012)

China is one of the developing Asian countries that has practiced composting in large scale especially in the big cities. Composting scenario in China has a significantly low environmental load point. This is mainly due to the large percentage of organic waste (63%) within the Chinese waste composition and the weighting of resource consumption as being the second most important impact category. Moreover, the Chinese survey respondents score the impact category of waste disposal as the lowest weight. This makes the volume of waste dumped in the sanitary landfill less significant.

The large-scale composting is practiced in large Chinese cities such as Beijing, Shanghai, and Urumqi. These plants are often registered as Clean Development Mechanism projects, receiving carbon credits[33]. The estimated compost fertilizer produced in the Chinese second scenario case study is 254 tonnes of waste for every 630 tonnes of waste treated. The recovered energy from landfill gas collection is 60 MWh for every 246 tonnes of non-inert, non-biowaste dumped in the sanitary landfill.

As an overall recommendation, scenario 2 has a lower impact and risk of failure compared to the other options. This scenario also offers a significant amount of energy recovery potential from the sanitary landfill.

4.5 Parameter sensitivity analysis

4.5.1 Category importance and electricity grid

To test how significant the weighting value from AHP questionnaire influence the result, figure 4.6 was generated. In this graph, the Indonesian weighting value was applied to all of the countries. There was not much change appeared. Global warming was the no. 1 most important category for India, but it is the no.2 most important category for Indonesia. As a result, scenario 1, or the most polluting option become less harmful. Energy depletion was the no. 1 most important category for both Indonesia and China. As a result, scenario 3, or the least energy consuming option becomes even more preferable.

[33] (IGES , 2012)

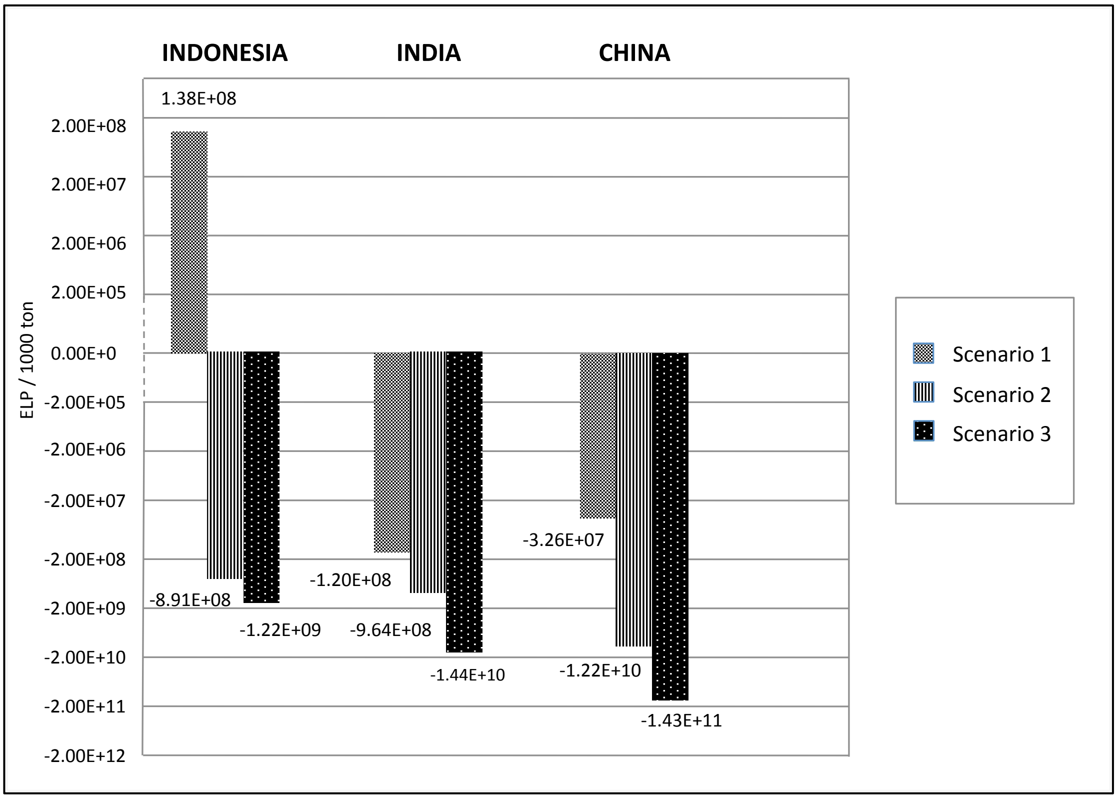

Figure 4.6 Sensitivity scenario 1: Indonesian category importance adapted to all countries

To test how significant the electricity generation mix influence the result, figure 4.7 was generated. In this graph, the Indonesian electricity grid mix was applied to all of the countries. It has significantly altered the results. Indonesia has the highest percentage of clean energy such as the hydropower and geothermal. Moreover, Indonesia do not have nuclear plant. Although nuclear plants do not emit carbon dioxide, sulfur dioxide, and nitrogen oxides from the power generation process, the uranium mining and the radioactive waste treatment consumes a lot of energy and fossil fuel emission. By applying Indonesian electricity grid mix; incineration performs very poorly in all of the countries. On the other hand, anaerobic digestion that is able to recover energy become less preferable than the composting option that is able to recover material. This is because the electricity grid mix is already rather clean.

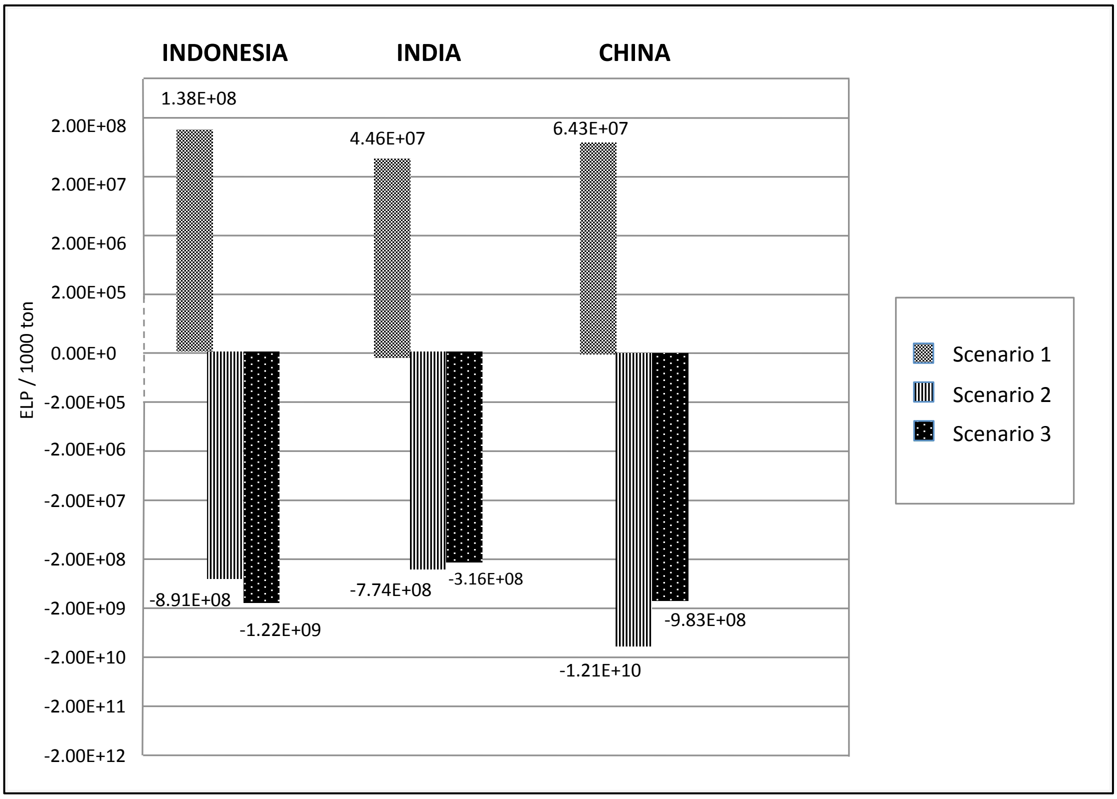

Figure 4.7 Sensitivity scenario 2: Indonesian electricity grid mix adapted to all countries

4.5.2 Actual practice and national policies

Currently, over 50% of the wastes generated in these three countries are still landfilled. In Indonesia, large-scale anaerobic digestion for municipal waste is not yet practiced. So far, the technology is only used for agricultural and animal farming waste because this technology is sensitive to the purity of the organic waste input. In India, the attempt to incinerate waste has been done, however they faced failures due to low calorific value. To increase heating value, RDF plants is technically feasible and the products are sellable to be mixed into the coal power plant. In China, large scale composting is practiced in big cities such as Beijing, Shanghai and Urumqi. Another way to understand the rate of success of technology implementation is by analyzing the existing CDM projects related to MSWM in the developing Asian countries. Table 4.6 summarized the medium to large-scale projects from the UNFCCC database. Only 1 AD project is found to be registered, this project is practiced in India. There are 7 composting projects, 9 incineration projects and 52 landfill gas collection projects. The composting projects are practiced in many Asian countries such as Indonesia, China, India and Bangladesh. Similarly due to the existing landfills, there are many landfill gas collection projects. There are 9 incineration plants but this practice is only found in China and India.

Table 4.6 Existing medium to large scale CDM projects related to MSWM in developing Asian countries

Technology	Number of projects	Scale	Countries	Example of name and year registered
Composting	7	50 – 600 TPD	Indonesia, China, India, Bangladesh	Composting of Organic Waste in Dhaka , 2006. Expansion of Nature and Waste Bhalaswa Composting Plant at Delhi, 2006 Bundled Waste Processing Facilities in India , 2009 Municipal Solid Waste (MSW) Composting Project in Urumqi, China , 2009
Anaerobic digestion	1	100 TPD	India	The TIMARPUR-OKHLA Waste Management Company Pvt Ltd's (TOWMCL) , 2007
Landfill gas collection	52	1 MW – 12 MW	Indonesia, Thailand, China, India, Bangladesh	Guangzhou Xingfeng Landfill Gas Recovery and Electricity Generation CDM Project , 2007 PT Navigat Organic Energy Indonesia Integrated Solid Waste Management (GALFAD) Project in Bali, Indonesia , 2007
Incineration	9	7.5 – 48 MW	China, India	Controlled combustion of municipal solid waste and sewage sludge and energy generation in Shaoxing City, People's Republic of China, 2009 Changshu Municipal Solid Waste Incineration Project, 2011 The TIMARPUR-OKHLA Waste Management Company Pvt Ltd's (TOWMCL) , 2007

Source: UNFCCC website 2012

There are a number of national law and regulations related to the Municipal Solid Waste Management practices and the technology recommendation that could be adopted in the country. Table 4.7 listed several of them and highlighted some of the significant content. Indonesia has a clean city program where award is given to the cleanest city. All of the cities that have been receiving awards are the one who practices composting in the neighborhood so that the residents are aware of the importance of separating organic waste to be made into fertilizer. These cities are greener too because more parks and green area are fertilized. In India, the MSW 2000 rule, recommends composting, RDF, and anaerobic digestion to minimize landfill space and to recover energy. In China, the circular economy principal is aggressively promoted, emission standards for pollution from incineration and control standards for urban waste for agricultural use are regulated.

Table 4.7 Regulations supporting MSWM technologies in Indonesia, India and China

Country	Laws and Regulation	Highlights from the Laws
Indonesia	Act of the Republic of Indonesia Number 18 Year 2008 regarding Waste Management Law Number 38 year 2007 regarding Responsibility of Central Government, Provincial Government and Local Government Act of the Republic of Indonesia Number 23 Year 1997 regarding Environmental Management Law Number 26 year 2007 regarding Spatial Planning Government Regulation Number 21 year 2006 regarding Policy and Strategy of MSW	Indonesia is implementing a program on municipal waste management called "Clean City Program/ADIPURA AWARD
India	Municipal Solid Waste (Management and Handling) Rules, 2000 Fertilizer (control) Amendment Order, 2006, followed by Fertilizer (Control) Third Amendment Order, 2009 – for quality control of compost from MSW Road Map of Management of Waste in India, 2010 Integrated Plant Nutrient Management using City Compost report of inter-ministerial task force, 2005 Environmental Impact Assessment Notification, 2006	Recycling is emphasized in MSW 2000 Rule Schedule II, SI. No.5 including recommendation if appropriate waste management by using the following technologies:Composting plus Refuse Derived Fuel (RDF) as a combination for optimal use of resources and minimization of landfill space, Waste to energy by RDF and Solid Recovered Fuel (SRF), Waste to energy by Anaerobic Digestion (AD) Use of recycled material
China	Law on the Prevention an Control of Environmental Pollution by Solid Wastes, effective 2005 Standard for Pollution Control on the Landfill Site for Municipal Solid Waste (GB16889-2008), effective July 2008 Standard for Pollution Control for Municipal Solid Waste Incineration (GB18485-2001), effective January 2002 Technical code for municipal solid waste sanitary landfill (CJJ17-2004), effective June 2004 The control standards for urban wastes for agricultural use (GB 8172 – 87), effective February 1998	China is promoting Circular Economy principal where it focuses on strategies for creating a circular flow of materials, and energy flows such as by providing economic measures that are favorable to 3R practices.

Source: IGES interim reports 2012, ADB consultants 2011, AIT/UNEP 2010

4.6 Summary

This chapter tried to analyze the LCA impact assessment using an ELP model for the very first time in the three selected Asian countries. Each goal that was set at the start of the study was achieved, and it was concluded that each country in this study gave different resulting scenarios of the lowest environmental load. The best result for the all of the countries is the scenario with composting. These are a reflection of what is most valued in the country based on the university students' questionnaire results, the waste characteristics, the country's annual emission and consumption, as well as the emission and energy recovered by each of the technology options. Additional to the LCA study, sensitivity analysis was conducted to show which of the incorporated parameters is the most influential. Results show that the electricity generation was the most influencing factor; by incorporating the Indonesian energy generation mix, the LCA study shows different result. The unique results for each country show that the ELP methodology has the potential to provide personalized results that incorporate technical and social considerations.

CHAPTER V

COST BENEFIT ANALYSIS OF MUNICIPAL WASTE COMPOSTING IN INDONESIA, SRI LANKA, AND CHINA FROM REAL DATA

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CHAPTER V

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5.1 Introduction

Technically, high moisture developing Asian countries municipal waste due to the high percentage of organic composition makes it more suitable for biological treatment instead of thermal treatment. Due to these facts, the biological organic waste treatment has an important role in reducing a significant amount of waste stream going to the landfill. Two commonly practiced biological treatment methods for organic waste are aerobic composting and Anaerobic Digestion (AD). AD method allows both material and energy recovery as compost fertilizer and electricity. However, AD plants are highly sensitive towards input quality. AD technology has been commonly used in Asia to treat animal manure, kitchen and agricultural waste because of the uniformity and purity of organic content. However, attempts to apply this technology to treat the rather complex municipal waste have faced difficulties due to low quality input[1]. These failures can be seen in Delhi, Bangalore, Lucknow and other cities in India[2]. Similarly, municipal waste AD plants in China also faced problems and operational difficulties[3]. Aerobic composting, on the other hand, is more forgiving towards input quality[4] and requires less investment and operational costs[5]. Studies from Indian experiences also revealed that both in rural and urban situations where space is available, composting is the better option[6]. Based on this analysis, we focused on the aerobic composting economic feasibility for organic municipal waste management option.

Although Asian developing countries have more experience with composting than AD, municipal waste composting is not a problem-free solution either[7]; there have been several factors, which could determine its sustainability. One factor that might have direct influence is the acceptance of its product in the market. Market acceptance of compost fertilizer relies on a wide range of criteria, including the price, quality and consistency of the product. It should also be free from contaminants such as heavy metals, glass, inert materials, and also plant and animal pathogens. The larger scale composting schemes often receive a large volume of mixed waste, which may contain contaminants[8] .The other source of possible income is Certified Emission Reduction (CER) if the plant is registered and approved as Clean Development Mechanism (CDM) project. However, less than 2% of the registered CDM projects are related to composting and all fall in the category medium to large scale composting plant category[9]. The smaller composting plants are not qualified to receive carbon credits due to insufficient greenhouse abatement potential set by the United Nations Framework Convention on Climate Change (UNFCCC) regulation[10]. In the modern world, composting sustainability influencing parameters are changing responding to the more complicated waste characteristics and social structure due to urbanization. These parameters are including where, how, and in what scale the composting should be conducted. The practice of traditional backyard composting is now moving

[1] (Mazumdar, 2012)
[2] (Ambulkar & Shekdar, 2004)
[3] (Zheng, 2012)
[4] (Hoornweg & Bhada-Tata, 2012)
[5] (Aye & Widjaya, 2006)
[6] (Sharholy, 2007)
[7] (Hargreaves, J.C., et al., 2008)
[8] (Williams, P. T. , 2005)
[9] (Fenhann, 2012)
[10] (Yenneti & Premakumara, 2011)

towards the bigger scale composting along with the increase of waste amount. Some Asian cities are doing the small scale - community based municipal waste composting whereas in the other cities centralized composting is more preferable. Despite of a growing number of municipal waste composting practices conducted in various manners, the information on analysis of municipal waste composting as a profitable business is lacking.

5. 1. 2 Objective and methodology

The objective of this study is to analyze factors that influence the economic feasibility of municipal waste composting plant and to find the range of plant capacity where the project might have higher opportunity to be financially sustainable based on the comparative analysis in the study.

In order to perform an economic analysis, Life Cycle Costing (LCC) and Cost Benefit Analysis (CBA) methodologies are often used[11]. A large number of studies have been conducted on waste related economic assessments, which often compare different type of technology options[12]. However, comparative study focusing on a single waste management method practiced in different capacities, particularly for the composting method is rare. Therefore, this study focuses on composting in various capacities from operative composting plants in five cities of three countries: Surabaya, Bali and Bekasi in Indonesia, Beijing in China, and Matale in Sri Lanka.

CBA results of this study represent only the discussed case study plants. However, the sensitivity analysis part has highlighted the most significant factors influencing the economic feasibility of a composting plant with different capacities. Therefore, this part could be used as an approximate economic guideline for investment in a composting plant in the developing countries in the Asian region.

CBA has been used for decision-making in projects and product and service assessments[13]. This study used a standard Net Present Value (NPV), Benefit Cost Ratio (BCR), and amortization time estimation formula widely implemented for waste related projects[14] to determine the economic feasibility of the project.

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+i)^t} \quad (1)$$

Where B as the benefit, C as the cost, i as the discount rate, and t as the time of the cash flow.

$$BCR = \frac{\sum_{t=0}^{n} B_t/(1+r)^t}{\sum_{t=0}^{n} C_t/(1+r)^t} \quad (2)$$

BCR is calculated as the present value of benefit divided by the present value of cost.

Finally, the amortization time is calculated as the year when the cumulative cash flow becomes positive during the lifetime of the project.

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[11] (Finnveden, 1999)

[12] (Reich, 2005)(Lutz, Lekov, Camilla, Chan, Meyers, & McMahon, 2004)(Ngoc & Schnitzer, 2009)(Menikpura, et al., 2012)(Aye & Widjaya, 2006)

[13] (Finnveden, Bjorklund, Moberg, & Ekvall, 2007)

[14] (Soeylemez, 2000)(Ali G., et al., 2012)(Bhatia, 1977)(Demir & Arisoy, 2007)(Mishan, 1972)

5. 2 Real data of composting plants in Indonesia, Sri Lanka, and China

5.2.1 Small scale composting plants

The amount of organic waste received in *Rungkut Lor* community-based composting plant in Surabaya is 0.6 tonnes per day and it produces 0.1 tonne of compost fertilizer daily. The capital costs of this include land acquisition, building, equipment and other planning and managerial initial cost of project establishment were subsidized by various organizations; the 190 m^2 land was donated by a university for this composting activity; the equipment and building construction costs were donated by Kitakyushu city government. Monthly operational costs are 125 USD for the labors and 60 USD for management. The average Indonesian inflation rate of 12.26% was incorporated to estimate the annual increase of operation and maintenance costs. Income sources are from selling the compost products with a price of 70 USD/tonne. Price increase of organic compost fertilizer made of green waste mixed with cattle manure in the market is 25%. For this particular plant, animal manure is not utilized and therefore a price increase of 10% is assumed. Table 5.1 summarizes the cost, benefit, and economical evaluation results of Rungkut Lor compost plant. The average Indonesian interest rate of 8.12% is incorporated for the NPV calculation.

NPV result for Rungkut Lor composting plant is 6496 USD, BCR is 1.08 and amortization period can be achieved in the 9th year. This means this project is feasible and although the achieved margin is very low, it is still financially profitable.

Table 5.1 Cost and benefit statement for Rungkut Lor composting plant

Investment cost[a]		**Operation and maintenance cost**	
Land	15,200	Personnel cost for composting per annum	1500
Building	800	Management cost per annum	720
Machineries & equipment	2481	Total cost per annum	**2220**
Fees[b]	919		
Total	**19,400**		
Benefit		**Economic evaluation results**	
Compost fertilizer per ton	70	NPV	-264.51
Production per annum (tonnes)	36.5	BCR	1.05
Composting kit per unit	1	Amortization period	9 years
Sold composting kit per annum (unit)	180		
Total benefit	**2735**		

[a] All investment cost were granted by the local university and Kitakyushu city government
[b] Fees for design, planning, authority submission, etc.
All figures are given in USD with conversion rate 1 USD = 9433 IDR

The Sri Lankan case study compost plant we selected for this study is located in *Matale* city with organic waste input capacity of 1 TPD. This plant produces 0.3 TPD organic waste fertilizer sold at 180 USD per ton. Other income sources are from selling the recyclables and the collection fee paid by the served residences and local markets. The investment costs including a 600 m^2 area of land whose leasing price would have been 3000 USD for the entire lifetime was granted by municipal government grants which *Sevantha* Non-Governmental Organization (NGO) who is running the project. The building construction cost of 23,000 USD and the equipment cost of 4700 USD were granted by United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP). To operate and maintain the plant, 2 personnel were hired as technician and worker who are paid at 60 USD and 125 USD salaries. The average Sri Lankan inflation rate of 10.4% was incorporated for the annual cost increase and an interest rate of 8.47% was employed as the discount rate for the NPV calculation. Similar to the Indonesian case, the estimated fertilizer price increase is 10%. This assumption is made based on the price increase of various kinds of fertilizers commonly used in plantations in Sri Lanka[15]. Table 5.2 summarizes the cost, benefit, and economical evaluation results of Matale compost plant. NPV result for Matale composting plant is 33,194 USD, BCR is 1.12 and amortization period can be achieved in the 6th year. Similar to the Indonesian case study, this project is feasible and although the achieved margin is rather low, it is still financially profitable.

Table 5.2 Cost and benefit statement for Matale composting plant

Investment cost		**Operation and maintenance cost**	
Land[a]	3000	Personnel cost for composting per annum	9600
Building	23,000	Management cost per annum	11,700
Machineries & equipment	4700	Total cost per annum	**21,300**
Fees[b]	3200		
Total	**33,900**		
Benefit		**Economic evaluation results**	
Compost fertilizer per ton	180	NPV	33,194
Production per annum (tonnes)	109.5	CBR	1.12
Selling recyclables per annum	720	Amortization period	6 years
Waste collecting service	3960		
Total benefits per annum	**24300**		

[a] Land is leased from the municipal government by *Sevantha* NGO
[b] Fees for design, planning, authority submission, etc.
All figures are given in USD with conversion rate 1 USD = 115 LKR

5.2.2 Medium scale composting plant

The medium scale composting plant selected for this study is located in *Temesi* village, Gianyar regency in Bali. This plant is registered as CDM project and receives 60 TPD manually separated waste. 85% or about 51 TPD of the received waste is organic and used for composting, and the remainder is disposed in the nearby final disposal[16]. Using forced aeration technique, the compost fertilizer product ratio is 30% from its input and sold at 106 USD per kg when bought in the 20 kg package and 53 USD/kg when bought in bulk[17]. The project also receives income from Certified Emission Reduction of 23 USD per ton CO_2-eq up to end of 2012 that decreases yearly by one USD and ends at 17 USD in 2018. The project investment costs were donated by Swiss Development Cooperation (SDC), USAID, Rotary Club

[15] (Gunathilake, H.A.J., 2005)
[16] (Kueper, 2009)
[17] (Zurbrügg, Gfrerer, Ashadi, Brenner, & Kueper, 2012)

Hamburg, Rotary Club Atlanta, JICA, and Bali hoteliers[18]. Table 5.3 summarizes the costs, benefits, NPV, BCR and amortization period for Temesi composting plant. Similar to the Surabaya case study, the discount rate of 8.12%, inflation rate of 12.26%, and fertilizer price increase of 10% were incorporated in the financial calculation. The results are 7,159 USD NPV, 3.05 CBR and 3 years amortization period.

Table 5.3 Cost and benefit statement for Temesi composting plant

Investment cost[a]		**Operation and maintenance cost**	
Initial investment cost	150,000	Personnel cost for waste separation	61,062
Expansion of the facility	180,000	Personnel cost for composting	57,882
CDM Registration	50,000	Diesel fuel	12,933
Total	**380,000**	Electricity	5,089
		Material and equipment service	10,919
		Administration	3,922
		Sales and marketing	6,573
		Depreciation	31,803
		Total	**190,183**
Benefit		**Economic evaluation results**	
Compost fertilizer (20 kg package) / kg	106 53	NPV	7,158,681
		CBR	3.05
Compost fertilizer (in bulk) /kg	21,900	Amortization period	3 years
Production per annum (tonnes)	123,820		
Benefit from fertilizer selling / annum	138,000		
CER per annum (in 2011)	**260,760**		
Total benefits per annum			

Sources: (Zurbruegg et al., 2012), (Kueper, 2009)
[a] Investment costs were donated by SDC, USAID, Rotary Club Hamburg, Rotary Club Atlanta, JICA, and Bali hoteliers
[b] Operation and maintenance cost are per annum
All figures are given in USD with conversion rate 1 USD = 9433 IDR

5.2.3 Large scale composting plants

Bantar Gebang composting site in Bekasi, Indonesia, treats the waste from the *Kramat Jati* central market in Jakarta containing vegetable, fruits, and fruit basket made of straw into compost fertilizer using the windrow composting method. Due to the demand, the product is pelletized and packed in 60 kg packages used for agriculture, such as, cassava plantation, palm oil plantation, and rice farms. The received amount of market waste is 200 TPD. The final product is 30 TPD of pelletized compost fertilizer. About 60 to 70% of the products are sold at 106 USD/ton. The residue is disposed in the nearby landfill or sold by scavengers for plastic recycling. 11 USD/ton waste tipping fee is paid by the Jakarta government. 20% of this fee is paid as land rent fee to the Bekasi city government and the remaining 80% is used for paying the plant operators, PT Godang Tua Jaya and PT Navigate Organic Energy Indonesia[19]. The tipping fee increases about 5% annually[20]. Costs related to transportation, such as, the 4-tonnes capacity trucks and the truck

[18] (Nakamura, H. et al., 2009)
[19] (Reich, 2005)
[20] (Joewono, B.N., 2010)

drivers' wages are paid by the cleansing department. 160 people, whom mostly used to work as scavengers in the nearby landfill, are paid 127 USD per person. Similar to the other Indonesian composting plants in this study, the discount rate of 8.12%, inflation rate of 12.26% and fertilizer price increase of 10% were assumed in the financial calculation. Results show that the NPV of this project is -1,867,812 million USD, CBR 1.28 and amortization period may be reached on the 7th year of the production lifetime. This implies that the project is estimated to be profitable but the present value of money would be negative.

Table 5.4 Cost and benefit statement for Bantar Gebang composting plant

Investment cost		**Operation and maintenance cost**	
Land[a]	2,437,719	Operational cost per annum	572,460
Building construction & Machineries	3,180,324	Maintenance cost per annum	152,652
		Depreciation	212,022
Total	**5,618,043**	Total cost per annum	**937,134**
Benefit		**Economic evaluation results**	
Compost fertilizer price per ton	106	NPV	-1,867,812
Sold fertilizer per annum (tonnes)	39,967.5	CBR	1.28
Tipping fee per ton[b]	8.9	Amortization period	7 years
Input waste per annum (tonnes)	73,000		
Total benefits per annum	**1,404,155**		

[a] Land is owned by Bekasi city government leased to Jakarta provincial government. Lease fee is 20% of the tipping fee. The figure is estimated payment for 15 years lifetime.
[b] Figure is 80% of the tipping fee that goes to plant operators (PT Godang Tua Jaya and PT Navigat Organic Energy Indonesia)
All figures are given in USD with conversion rate 1 USD = 9,433 IDR

Beijing Nangong composting plant receives 638 TPD of municipal waste, in which 172.6 TPD is used as landfill cover soil and 465.4 TPD is processed into compost fertilizer using tunnel-composting systems with forced aeration technology. The sellable product is 65.7 TPD. Depending on the quality, price ranges from 7.8 to 12.6 USD/ton. The remainder is given to farmers with no charge. The government of Beijing granted a land area of 66,000 m^2. The investment cost for machinery, equipment and building was 26.6 million USD. The operation and maintenance cost is fully subsidized by the government of Beijing which is 15.86 USD per ton waste treated as tipping fee. Table 5.5 summarizes the costs, benefits, NPV, BCR and amortization period for Nangong composting plant. For the annual operation and maintenance cost calculation, the employed China inflation rate is 4.3% and the discount rate employed for NPV calculation is 6.5%. The municipal waste compost fertilizer price increase is assumed to be 10**%**.

Table 5.5 Cost and benefit statement for Nangong composting plant

Investment cost[a]		**Operation and maintenance cost**	
Land[b]	51	Personnel cost per annum	1,885,014
Building & machineries	26.6	Water cost per annum	11,310
Total	**77.6**	Electricity cost per annum	339,303
		Depreciations	1,444,193
		Total cost per annum	**3,679,820**

Benefit		Economic evaluation results	
Compost fertilizer per annum	546	NPV[a]	-123.5
Tipping fee per ton	15.8	CBR	0.77
Received waste per annum (ton)	232,900	Amortization period[c]	Never
Total benefits per annum	**3,680,366**		

[a] Figures are in million
[b] Land was granted by the government of Beijing, land price estimated from the current Beijing land price discounted to the year 1998 when the plant was established

The NPV result is -123.5 million USD, CBR is 0.77 and amortization time cannot be achieved throughout the 15 years assumed lifetime. The results imply that the project is not financially profitable. Additional cost arising in a large scale composting plant is the transportation cost. However, Nangong composting plant does not bear this cost because it is borne by the government appointed Transportation Company. Similarly, the transportation cost to Bantar Gebang plant is borne by the cleansing department.

5. 3 Financial results and discussions

5.3.1 NPV, CBR and Amortization time

All of the NPV, CBR and Amortization time results from the different capacities of composting plant in this study show a similar trend. The NPV and BCR value increases as the capacity increase to 51 TPD (Bali, Temesi plant) and decrease in the bigger capacity composting plant case studies in Bekasi (200 TPD) and Beijing (638 TPD). Similarly, the amortization time becomes lower as the plant capacity increases to 51 TPD and then decreases as the capacity increases.

Table 5.6 NPV of different composting plant capacities

Capacity (TPD)	NPV (USD)
0.6	-264.51
1	33,194
51	7,158,681
200	-1,867,812
638	-163.6

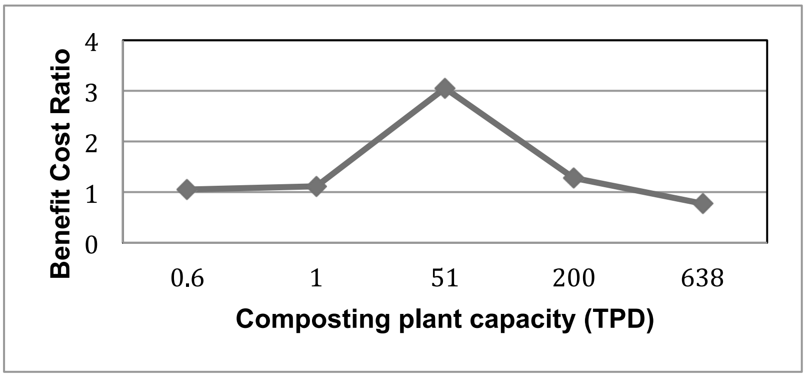


Figure 5.1 Relationship between plant capacity and Benefit Cost Ratio

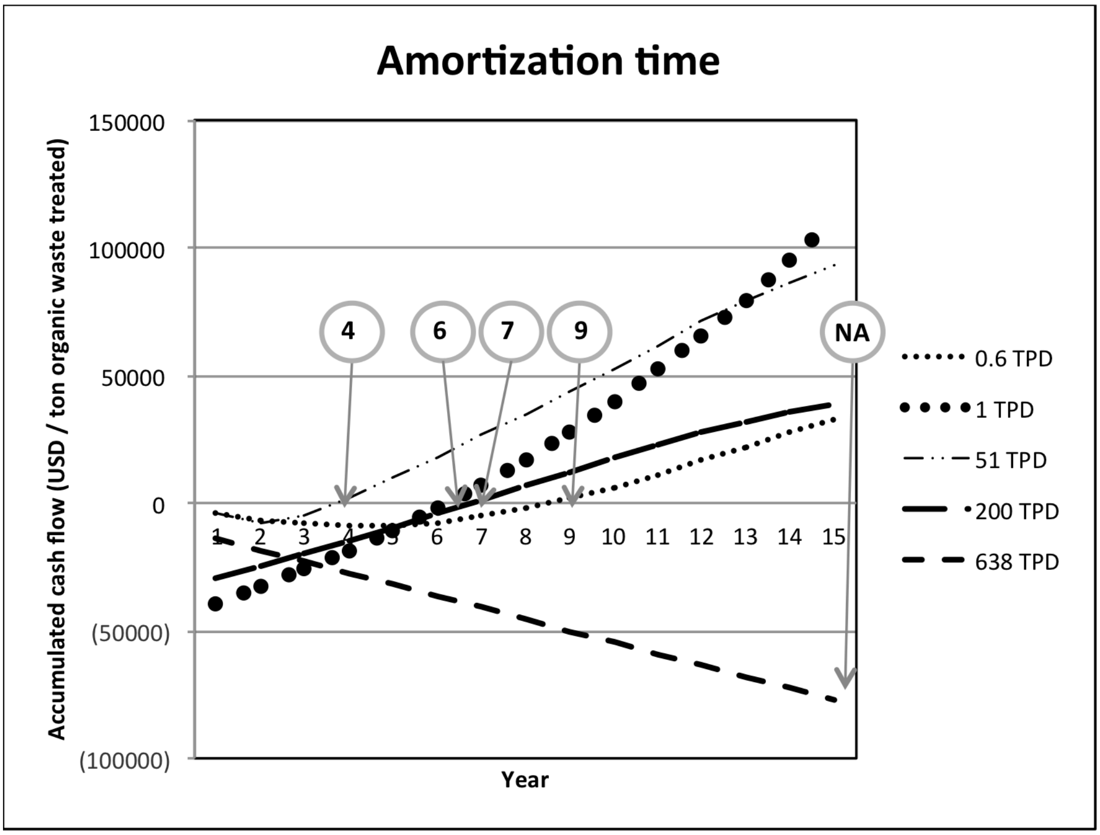


Figure 5.2 Amortization time of different composting plant capacities

5.3.2 Cost and benefit components

The local government, universities, and organizations subsidized the investment costs in the selected studies. The estimated investment cost per ton organic waste treated if it were not subsidized is shown in Figure 5.3. The highest investment cost is shown in Beijing (638 TPD). The land cost in Beijing is extremely high compared to the rest of the regions, as it is the capital of China where land is scarce and population is abundant. Bekasi, although facing similar problem is much cheaper because it is paid on a lease basis, which only cost 20% of the tipping fee, paid by the Jakarta provincial government (the waste source) to the Bekasi city government (the plant location). Similarly the Sri Lankan (1 TPD) case study also acquired the land by lease. However, building construction cost is much higher in Sri Lanka (23,000 USD) than in Surabaya (800 USD), which results in a rather similar total investment cost between these two small-scale plants.

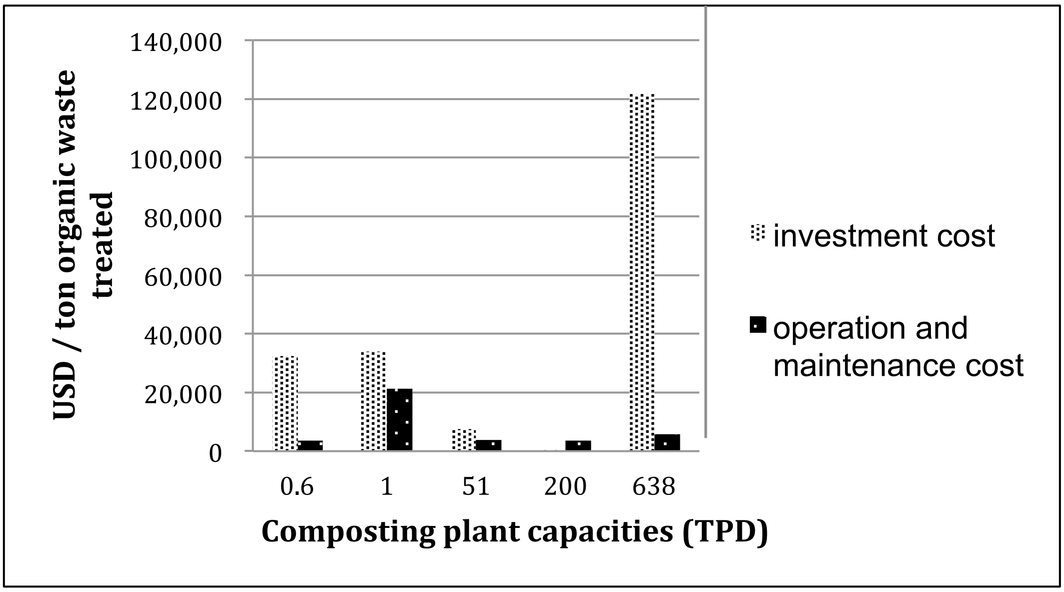
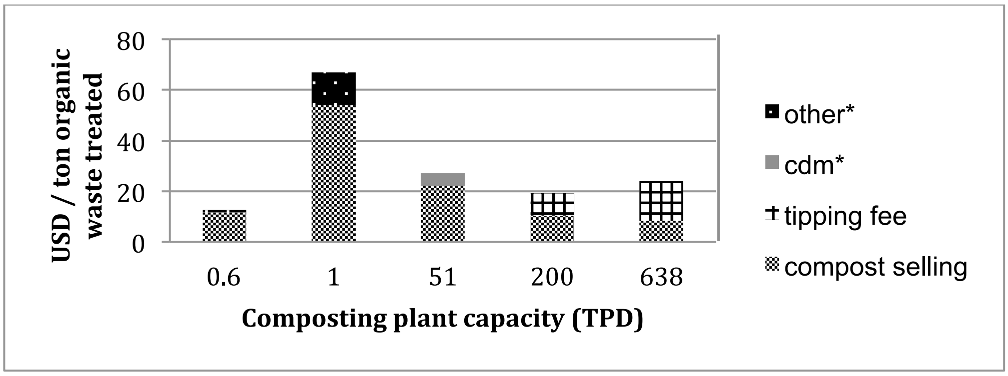


Figure 5.3 Cost components for different composting plant capacities

The operation and maintenance cost per ton of organic waste treated does not show any particular pattern; it is higher in the 1 TPD plant than the rest of the other plant. The operation and maintenance cost is highly dependent on the technology used in the plant. When the traditional open windrow is practiced, operation requires more manpower. When sophisticated technologies such as forced aeration aerobic process is practiced, more electricity is required. This is true in the Bali (51 TPD) and Beijing (638 TPD) composting plants. The 200 TPD plant in Bekasi used the open windrow method and further pelletized the product, which caused it to become an energy and manpower intensive process. The operation and maintenance costs also rely on the electricity price. The electricity price is highly subsidized in Indonesia[21] therefore it is less costly.



*Other: collection fee, selling recyclable material and composting kit received by the small scale plants.
* CER: accumulated revenue from the 10 years CDM contract divided by the weight of organic waste treated throughout 15 years of assumed plant life time

Figure 5.4 Benefit components from different composting plant capacities

The sources of income are slightly different in the various scale of composting plants discussed in the study, however all plants are receiving income from selling the product. Smaller plants have better pricing opportunity because quality control is

[21] (International Institute for Sustainable Development, 2012)

easier. Moreover, the organic waste source is household kitchen waste which is relatively pure organic and sorting could be done rather early at the source. As the plant capacity increases, quality becomes lower thus acceptable market price is reduced. Attempt to increase value is done by the Bantar Gebang, Bekasi (200 TPD) plant by pelletizing the product. The plant manager reported that the product is widely used for large-scale plantation across the country.

In this study, tipping fee is only received by the large-scale composting plants, whereas CER is only received by the medium scale composting plant. The tipping fee plays a significant role in the financial sustainability of the Beijing Nangong (638 TPD) plant as it covers the necessary operational cost. However, this practice is not necessarily true for the rest of China. Only when the local government could afford the required cost, a normal daily operation may be conducted. Similarly, the tipping fee received by the Bantar Gebang plant plays a significant role in the financial sustainability of the composting plant.

5.4 Sensitivity Analysis

All of the composting plants presented in this study received some kind of support either from the government, university, NGO or other kind of institution and organization. Pessimistic scenarios were constructed to see how the plants would perform under the absence of these financial supports. In the case studies of the small-scale composting plant, grants for the initial investment is assumed to be non-existing, replaced by a loan from the bank with interest rate of 5% annually. Similarly, the medium-scale composting plant's received grant on the investment cost and the CER benefits are assumed to be non-existing. Moreover, the investment and enlargement cost of the medium-scale plant is assumed as gained from bank loan with interest rate of 5%. Finally, the pessimistic assumption for the large-scale plants is the elimination of financial support in the form of land, tipping fee, and coverage of transportation costs.

Results showed that the small-scale Rungkut Lor plant in Surabaya (0.6 TPD) would not be feasible in the pessimistic situation; cash flow would become negative throughout the lifetime and amortization time would not be achieved. On the other hand, under the same situation, the Matale plant in Sri Lanka (1 TPD) would still be profitable with CBR of 1.12 and amortization period would only be delayed by 2 years. The high price received for the sold fertilizer is a significant factor in sustaining the plant. However, NPV would become -75.058 USD indicating this project would have not been financially recommendable under the pessimistic scenario constructed.

Pessimistic scenario result for the medium scale composting plant (51 TPD Temesi plant), shows a postponed amortization time from 3 years to 13 years, reduced CBR from 3.05 to 1.3 and reduced NPV from 7,158,681 to -3,291,003 USD. This implies that although it would be resulting in a very thin margin, the project may still be profitable under the assumption of non-existence of any kind of external financial support.

Finally, the results from the large-scale composting plant pessimistic scenario, shows that both case studies in Bekasi and Beijing do not show feasible results, indicated by the negative NPV, the low CBR (lower than 1) and amortization time would not be achieved throughout the entire lifetime.

5.5 Summary

This study was an effort to investigate the significance of each influencing factor of the financial feasibility of organic content from the municipal waste in developing Asian countries. The most challenging part of this study was data collection because often plant managers are reluctant to give the real figure of costs and benefits due to confidentiality issue. However, site visits and continuous communications maintained were able to solve the problem.

The results of this study showed that the medium scale (51 TPD) composting plant has a better opportunity to be financially feasible; waste input and product quality are more controllable, there is a possibility to gain benefit from CER and the project can make use of the existing landfill complex and transportation. When quality could be enhanced such as by manually separating organic waste done in Bali or pelletizing the waste in Bekasi, market acceptance might increase. With good market acceptance, the Bali plant was predicted to be able to sustain itself even without benefit from CER. Another strategy conducted was an agreement by the Bantar Gebang plant with the Department of Agriculture, where a significant amount of the product is used for plantations. The government and institutions' roles, such as, providing investment cost of the small scale composting plant and providing tipping fee for the large scale composting plants, are significant in determining the economic feasibility of the plants. Awareness of the governmental policy makers to these findings and their effort to alter their policy framework accordingly will lead to more sustainable municipal waste management in the developing Asian countries. Moreover, better soil condition, sustainable agricultural production, and new job opportunities are only few of additional benefits from a sustainable municipal waste composting plant.

Recommendation for further study is to include the transportation and environmental cost. This approach will provide a more holistic idea about how much the entire process would have cost if externalities were internalized.

CHAPTER VI

COMPARATIVE ANALYSIS OF AHP AND TEXT MINING APPROACH FOR ELP METHOD WITH APPLICATION IN MSWM FOR THE DEVELOPING COUNTRIES

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CHAPTER VI

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6.1 Introduction

6.1.1 Research objective and methodology

Environmental Load Point (ELP) is an ecological sustainability assessment tool developed in Waseda University, Nagata laboratory to measure the burden that the environment has to bear during a certain process. In this study, the processes are several ways of waste treatment using the European technology including incineration, recycling, and sanitary landfilling. Each of these treatment processes has inventory database, which is the result of research in the actual process in a certain location. This study uses ecoInvent database that usually are used in commercial Life Cycle Assessment (LCA) software such as simaPro, Umberto, and Gabi. With ELP methodology, the database can be calculated manually by simple program like Microsoft Excel so that it improve the transparency of the calculation as well as allowing other parties to double check the results and the objectivity of the study. The ELP has nine impact categories. These categories are energy depletion, ozone depletion, acid rain, resource scarcity, air pollution, ocean and water pollution, problem of waste disposal, and ecosystem effect. Each of the impact categories has indicators, such as oil, natural gas, and coal for energy depletion; CH4 and CO2 for global warming; chlorofluorocarbon and hydrofluorocarbon for ozone depletion; NOx and SOx for acid rain; Fe, Ni, Sn, Au, and Ag for resource scarcity; PM10 and PM2.5 for air pollution; 137 biological oxygen demand (BOD), chemical oxygen demand (COD), and suspended solids for ocean and water pollution; solid waste for problem of waste disposal; and ecosystem effect. Each of the impact category has indicators such as oil, natural gas and coal for energy depletion, CH_4 and CO_2 for global warming, Chlorofluorocarbon (CFC) and Hydrofluorocarbon (HFC) for ozone depletion, NO_x and SO_x for acid rain, Fe, Ni, Sn, Au, Ag for resource scarcity, PM_{10}, $PM_{2.5}$ for air pollution, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Suspended Solids (SS) for ocean and water pollution, solid waste in problem of waste disposal, petrol, benzene, dioxin for ecosystem effect. The complete list of indicators comprises 186 items. Table 6.1 shows the impact categories and the indicators relevant to this study that were incorporated for analysis.

Table 6.1 ELP impact categories

Impact Category (j)	Indicators (k)	Weight coefficient (C)[a]
Energy Depletion	Oil, natural gas, coal	0.089
Global Warming	CO2, CH4	0.082
Ozone Depletion	(not used in this study)	0.098
Acid Rain	NOx, SOx	0.086
Air Pollution	SO_2, NO_2, CO, $PM_{2.5}$, PM_{10}	0.072
Resource Consumption	Iron (Fe), Nickel (Ni), Tin (Sn), Aluminimum (Al), Gold (Au), Silver (Ag)	0.134
Ocean and Water Pollution	BOD5, COD	0.135
Problem of Waste Disposal	Slag, Residues	0.107
Ecosystem Influence	(not used in this study)	0.197

[a] fixed by laboratory and literature result[1]

The mathematical equation for LCA model consists of a three-steps calculation. The first step is determining the annual load (A). A is the result of multiplication of weight coefficient of each item in impact category fixed by the laboratory literature (C) listed in table 6.1 with the national annual consumption and emission (TQ).

$$A_j = \sum_k (C_{j,k} \times TQ_k)$$

Aj: Annual load in j impact category

$C_{j,k}$: Weight coefficient for k indicator in j impact category

TQ_k: Annual consumption or emission for k item

Suffix j: Impact category

Suffix k: indicator in impact category

Equation 1. Annual load formula

The second step is to calculate Environmental Load Factor (ELF), which is the result of multiplication between coefficient (C) listed in table 6.1 and the weighting value (W), divided by annual load (A) from equation 1 results. The weighting value (W) is derived from survey and questionnaire of the related stakeholder or community.

$$ELF_k = \sum_j (C_{j,k} \times W_j / A_j)$$

ELF_k: Integrated coefficient for k item

W_j: Weight coefficient (category importance) from questionnaire in j impact category

$C_{j,k}$: Weight coefficient for k indicator in j impact category

Aj: Annual load in j impact category

Suffix k: indicator in impact category

Suffix j: Impact category

Equation 2. Environmental Load Factor formula

The final step is multiplying ELF with the total indicator's consumption or emission of the process or production of the related MSW technologies from ecoinvent database to get the Environmental Load Point as the final output. Equation 3 shows the formula used for this calculation.

$$ELP_i = \sum_k (ELF_k \times Q_{i,k})$$

ELP_i: Integrated Indicator

ELF_k: Integrated coefficient for k indicator

$Q_{i,k}$: Total consumption or emission for k indicator in process i

Suffix i: Process or product

Suffix k: indicator in impact category

[1] (Nagata, Ureshino, Matsuda, & Ishikawa, 1997)

Equation 3. Environmental Load Point formula

The main objective of this chapter is to find out the strength and weaknesses of weighting coefficient collection approaches. The two approaches were applied to three developing Asian countries, namely Indonesia, India, and China. From the analysis, it is expected to find which of the methodologies are appropriate for application in which field.

6.2 Weighting coefficient data collection methodology

In this study, two approaches; Analytic Hierarchical Process (AHP) and text mining method was adopted to derive weighting coefficient. The respondents of the first approach are groups of people belonging to educational insitution. The second approach gathered information from the local online newspaper.

6.2.1 AHP approach

AHP is a mathematic-psychology based structured survey approach commonly used in higher institutes of engineering. Table 6.2 shows a sample of AHP questionnaire used to determine category importance. The blue area was filled-in by respondents and the grey area generate the opposite number of importance automatically. Respondents may choose nine different level of importance. The sum of each category result is being averaged relative to the rest of the categories and the value becomes the weighting coefficient.

Table 6.2 AHP questionnaire sample

	ELP 9-category	B									Definition of grade importance	
		Energy drain	Global warming	Ozone depletion	Acid precipitate	Resource consumption	Air pollution	Water pollution	Waste disposal	Ecosystem effect		
	Energy drain										9	A is extremely more important
	Global warming										7	A is much more important
	Ozone depletion										5	A is more important
	Acid precipitate										3	A is a bit more important
A	Resource consumption										1	A is almost the same as B
	Air pollution										1/3	B is a bit more important
	Water pollution										1/5	B is more important
	Waste disposal										1/7	B is much more important
	Ecosystem effect										1/9	B is extremely more important

6.2.2 Text mining approach

The second methodology used to find category of importance in this study was text mining. Text mining was done using Google web search Engine. The engine was set to show the number of news that contains the word from the nine categories (Energy drain, Global warming, Ozone depletion, Acid rain, Resource consumption, Air pollution, Ocean and water pollution, Problem of waste disposal, Ecosystem effect) found in Indonesian language online news published in one year. Each of the search result is divided by the total number of result of all category and then multiplied by 100% to show how significant a category as compared to rest of the categories.

$$W_j = \frac{\sum_{m=m1}^{mx} j_m}{\sum_{m=m1}^{mx} j_{x,m}} \times 100\%$$

Wj Weight coefficient (category importance) from the media in j impact category

Jm The number of times j impact category is mentioned in media m in a year

jx The sum of number of times of all impact categories mentioned in media m in a year

*m*1 The first media being text-mined

x The last media being text-mined

Equation 4. Text mining formula

6.4 Comparative analysis between AHP and text mining

Observing the nature of AHP and text mining, AHP can only get result from a number of people being surveyed. A range of 10 to several hundreds would be feasible to do. AHP targets on the group of people who belongs to a certain organization, company, or institution, therefore motivation and background are easily assessed. On the other hand, text mining may be conducted to a number of online media including newspapers, bulletin, or even blogs. The motivation and background of the information resource is not easily accessed. A media could belong to a certain political or religious party having a certain view on the environmental topics.

6.4.3 AHP and text mining survey results from Indonesia, China and Thailand

Both AHP and text mining were conducted in Indonesia, China, and Thailand. The Author did the Indonesian survey and the Thailand text mining. Other members of Nagata Katsuya and Onoda Hiroshi Laboratory collected the other results. Lin Li collected China results and Hirokazu Shimizu collected Thailand AHP results.

Indonesia

The Indonesian AHP questionnaires were distributed to two groups of respondents. The first group was the Institute of Technology Bandung (ITB) University students. There were 145 students, mainly from engineering major, filling the questionnaire. The second group of AHP respondents from Indonesia was 45 Eco school' teachers from three different districts: Cibubur, Depok, and Banten. For detailed respondents answers, see appendix A.

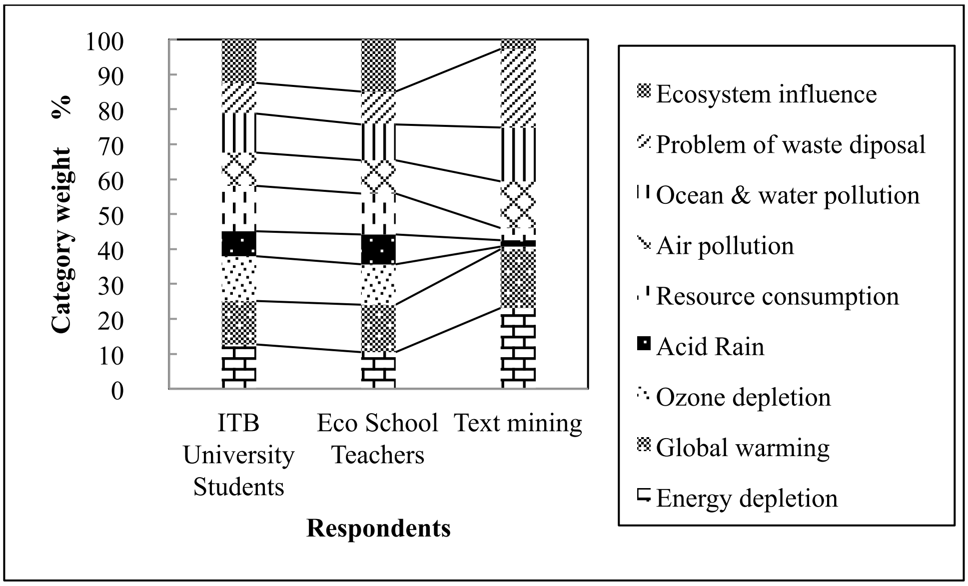

Figure 6.1 Indonesian category weight results from AHP and text mining approaches

ITB university students give higher importance in resource consumption, ozone depletion and energy depletion. Eco-school teachers give higher importance to resource consumption, ecosystem effect, and global warming. It is interesting to analyze that despite the significantly higher exposure of news about waste problem in the media, it does not show in the interest of the two groups of respondents as priority. The reason of clash of interest might be because Eco-school teachers already taken care of their waste at school by waste segregation activity and then collected by scavengers for recycling. The school's organic wastes are made into compost fertilizer as one of the student's activities. Eco-school teachers also observe the ecosystem on a daily basis in their nature-based school so that they could see the changes in the environment first hand. Thus, ecosystem effect is put as the first priority. ITB university students who put priority on resource consumption and energy drain are mainly coming from physics engineering who are very much into oil and gas related issues. They are very well aware of the threats of resource depletion and the impact on energy scarcity. On the other hand, those who are coming from environmental engineering contribute to the priority concern on ozone depletion in relation to global warming potential.

China

AHP questionnaire were distributed to 278 Beijing and Dalian University students in China. The text mining were conducted to 12 local newspaper published between the year 2005 to the year 2011. The results showed that university students put higest importance on energy depletion, resource scarcity, and global warming. Whereas, the newspaper results showed that waste problem, resource consumption and energy depletion are the rather popular topic in the country.

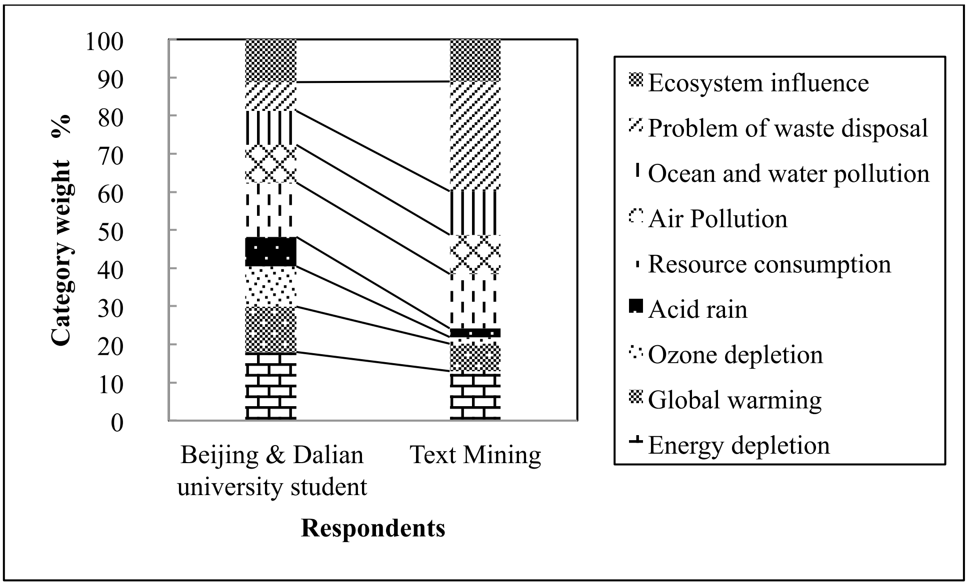

Figure 6.2 Chinese category weight results from AHP and text mining approaches Source: (Li, 2011)

The problem of waste disposal appeared as the most important aspect in the text mining result. Disposal from production in factories, which were not properly treated, pollutes the environment and gained attention of the media. The circular economy policy introduced in China increased people's awareness on the importance of properly maintaining waste and recycling waste for material recovery, which is address by the second most important result: resource consumption. On the other hand, the direct questionnaire to students addressed a more popular issues such as global warming and energy depletion which affects directly on the electricity price.

Thailand

AHP questionnaire were distributed to 100 Chulalongkorn University students in Thailand. The text mining were conducted to 3 local newspaper published in the year 2010. The results showed that university students put highest importance on resource scarcity, ecosystem effect, and global warming. Whereas, the newspaper results showed that energy depletion, resource consumption and waste problem are the rather popular topic in the country.

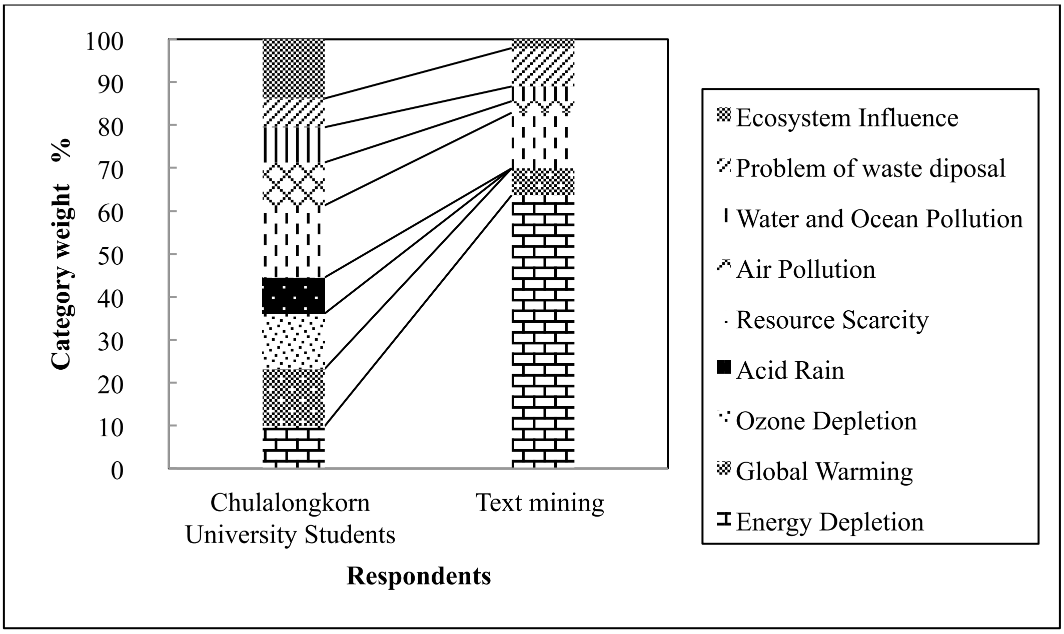

Figure 6.3 Thailand category weight results from AHP and text mining approaches

University AHP questionnaire result source: **(Shimizu, Nagata, Hansuebsai, & Kiengprakong, 2012)**

The extremely high importance weighted to energy drain is due to two events taking place in the country. The first one is the Petroleum Authority of Thailand (PTT) company joined force to Open Renewable energy Asia in 2010. The second one, it was the year when Thailand's Renewable Energy Opportunities & Challenges paper was released by the ministry of energy for future energy plan. These two events shows the increase of environmental awareness, not only in the governmental body but also among companies.

6.4.4 Results and discussions

The text mining results from Indonesian between the national newspapers and the local newspapers showed different weight value on the impact categories. Figure 6.4 is the result from the national newspapers and figure 6.5 is the result from the local newspapers. The national newspapers published more article discussing about energy depletion on the other hand, the local newspaper published more article about waste problem. Waste problem and resource consumption seem to get more attention in the local newspapers as compared to the national one. This may explain why small-scale composting activities are more successful in the smaller community. News about electricity price increase, gasoline and fuel scarcity is more often discussed in the national newspapers. For detailed number of times the keywords appeared in each newspaper, see appendix B.

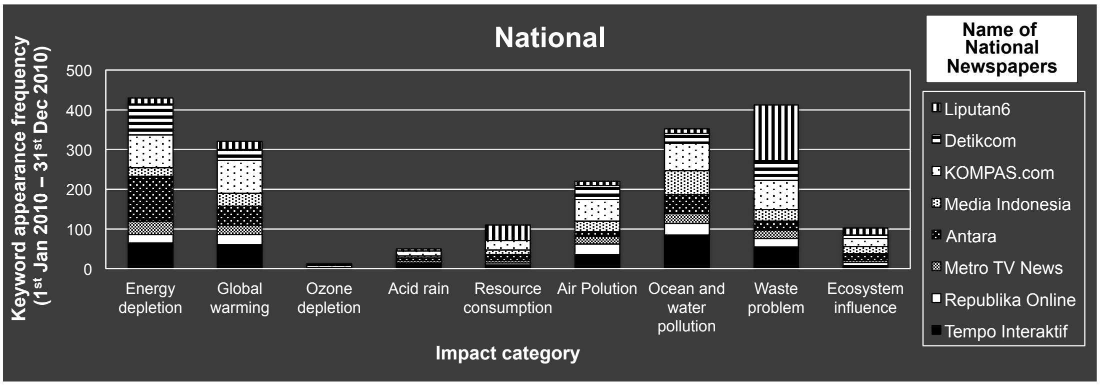

Figure 6.4 Text mining result from Indonesian national newspaper

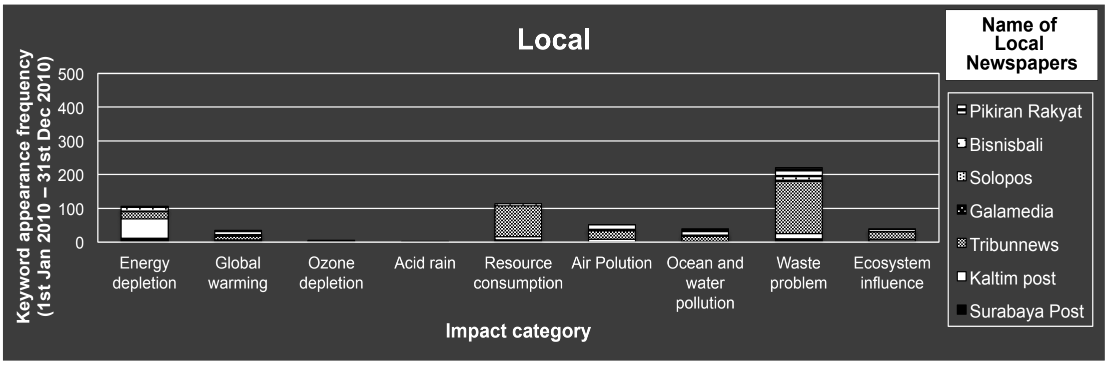

Figure 6.5 Text mining result from Indonesian local newspaper

The text-mining results of the three countries are energy depletion, ocean and water pollution, waste problem, and resource consumption. These are among the most concerned environmental issues within the ELP impact categories. To understand the logics behind the judgments of the respondents and the surveyed media, graphs are provided based on the latest available World Bank data bank, UN data, and the related institutes.

Table 6.3 Results of AHP questionnaire and Text – mining

Country	Top 3	Bottom 3
Indonesia	Energy depletion	Acid rain
	Problem of waste disposal	Resource consumption
	Ocean and water pollution	Ozone depletion
China	Problem of waste disposal	Acid rain
	Resource consumption	Global warming
	Energy depletion	Ecosystem
Thailand	Energy depletion	Ecosystem
	Resource consumption	Air pollution
	Problem of waste disposal	Ocean and water pollution

In terms of energy use, the World Bank databank 2012 shows that the three countries have an increasing trend year by year. Additionally, the Indonesia Energy Outlook and Statistics from the University of Indonesia 2006 stated that although the Indonesian national production has been sufficient for domestic use, it is predicted that the consumption and import rate would be increasing in the near future; on the other hand, the production and export rate are expected to decrease. In terms of waste collection, according to the UN data 2012, the amount of waste collected in China, Indonesia and Thailand are in the increasing manner. In terms of the global warming issue, it is also clear that the CO2 emission-per-capita in the three countries are increasing. For resource consumption, the iron and steel institute of Thailand, 2012, reported that the export is rather stable and the import is rather fluctuates but also in the increasing manner.

6.4.5 Features of AHP and text mining

Results from the three countries using AHP approach showed that resource consumption is among the top 3 environmental problems. This is highly related to population growth in these emerging countries as well as the limited resources available to accommodate this growth. People are sensitive to primary consumer goods price increase in the market. On the other hand, waste problem is brought up as one of the most discussed environmental topic in the media within the three countries. News related to landslides, flooding, health issues due to improper waste management are often highlighted when incidents happens in the country. The topic of sustainable MSWM is very much related to material and energy recovery. The text mining result focus more on problem whereas the AHP gives potential and opportunity of waste utilization.

Table 6.4 Comparison table between AHP and text mining approach

	AHP	Text - mining
Methodology	AHP approach, acquires weighting Coefficients based on the opinion from a certain group of people with specific interests or occupation.	Text-mining approach, acquires weighting coefficient based on counting key words appearance frequency in the media in a fixed period of time.
Advantages	Results reflect the respondent past experiences and future expectation based on their knowledge and experiences.	Results reflect a wide perspective from the national or regional trends and interests.
Disadvantages	Represent result from a limited number of sample groups. Risk of subjectivity.	Represent result from a limited period of time. Risk to capture only Occasional / temporary hypes or events occurring in the particular year.
Applicability	To projects that require long-term consideration and where using results from a group of people as representative is acceptable.	To projects where long term Considerations are not vital but require a national / regional perspective

6.5 Summary

The AHP approach acquires weighting Coefficients based on the opinion from a certain group of people with specific interests or occupation. The advantage of AHP approach is that its results reflect the respondent past experiences and future expectation based on their knowledge and experiences. The disadvantage of AHP approach is that it represents result from a limited number of sample group risks of subjectivity. The text-mining approach acquires weighting coefficient based on counting key words appearance Frequency in the media in a fixed period of time. The advantage of this approach is that it reflects a wide perspective from the national or regional trends and interests, while its disadvantage is that it only represents result from a limited period of time. This risks tcapturing only Occasional / temporary hypes or events occurring in the particular year. AHP is the more applicable approach to projects that require long-term consideration and where using results from a group of people as representative is acceptable. On the other hand, text-mining is the more applicable approach to projects where long term considerations are not vital but require a national / regional perspective.

CHAPTER VII

CONCLUDING CHAPTER

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7.1 Conclusion of the study

This study has given an in-depth analysis on the topic of municipal solid waste management in the developing countries in Asia. After a solid knowledge data establishment in the first second chapter, problems and challenges were identified including the need of more sustainable technology for waste treatment. On the third chapter, tools to measure the environmental impact of the possible technology adaptations were compared and ELP was found to be valid and able to represent the importance of waste disposal problems. The study continued with the application of ELP with AHP approach to several case studies of the developing countries in Asia. Results of this chapter showed that composting is superior to the other waste treatment technology options, therefore, further analysis were conducted in the fifth chapter. Cost Benefit Analysis for composting was performed in the fifth chapter. The sixth chapter contained a proposal of weighting approach alternative for the ELP methodology and it was found that the text mining approach is able to highlight the problem of waste disposal and may cover a greater area of respondent.

Some of the specific findings, achievements and policy recommendations made in this study are:

1. There are several life cycle assessment tools that have been developed especially in the European and American countries. These methodologies are modeled to fit the situation of the place where they have been developed. On the other hand, the application in the developing Asian countries are using generic data from the European or the Japanese inventory database due to lacking of local research to provide the database.
2. The developing Asian countries have organic waste as the biggest fraction of their municipal waste composition. The technologies that have been practiced are including landfilling, composting, RDF, incineration, and small-scale biogasification. Common waste characteristics are high moisture, low calorific value and mixed collection. This characteristic adds to the challenge of energy and material recovery. Composting was found to be the most low risk method to minimize waste going to the landfill in the case of developing Asian countries.
3. In order to implement a new technology, environmental assessment has to be done. The ELP methodology developed in the study for this purpose employs AHP and text mining as two alternative approaches to weight the importance of each impact category within the ELP model. AHP is limited to a limited group of respondent but it may incorporate the predicted future and historical past thoughts and experience of the respondents. On the other hand, text mining has wider scope of respondents that might even represent the nation but it is limited to the set period of time and objective to the hype and trend of topics discussed in the society at the time of publication.
4. Among the technology proposed for municipal waste management in case studies of different countries assessed by ELP, composting has the medium environmental impact and more history of success story as compared to the other technologies offered in the constructed scenarios. Therefore it was selected as the recommended technology for the developing countries in the Asian region to treat the municipal waste.

5. Economic assessment was offered as cost and benefit analysis for composting. The result of this chapter showed that in order to sustain a municipal waste composting, the recommended capacity is around 50 TPD and pre sorting of the organic waste is required to improve the quality and eventually increase the market acceptance of the product. The other recommendation made in this chapter was to introduce tipping fee in the larger capacity composting and grants of land for the smaller scale composting to improve the economic feasibility of the plant.
6. There are various ways to derive the weighting values to be used in an LCA study. In the ELP LCA methodology, two weighting approaches were presented in this study. It was found that the AHP approach was able to capture past experience and the future perspective of the respondent. On the other hand the text mining was able to represent the opinion of a bigger number of respondent.

Other achievements

In addition to the peer-reviewed journal articles published throughout the making if this dissertation, several publications were made for international institutions and local magazine. These are working paper, policy paper, and magazine publication. The first chapter of this thesis contributed to the publication “Toward sustainable municipal organic waste management in south asia: A guidebook for policy makers and practitioners” published by the Asian Development Bank (ADB), funded by Australian government. The third chapter of this thesis contributed to the working paper of the European Union Institute in Japan (EUIJ), entitled “Sustainable Approach of Municipal Solid Waste Management for Developing Countries: Reflecting on Japan – EU Knowledge and Technology”. And an article published in Indonesian Magazine, “Majalah Philantropy”, March edition, titled “Waste-to-Energy driving policy in Europe”.

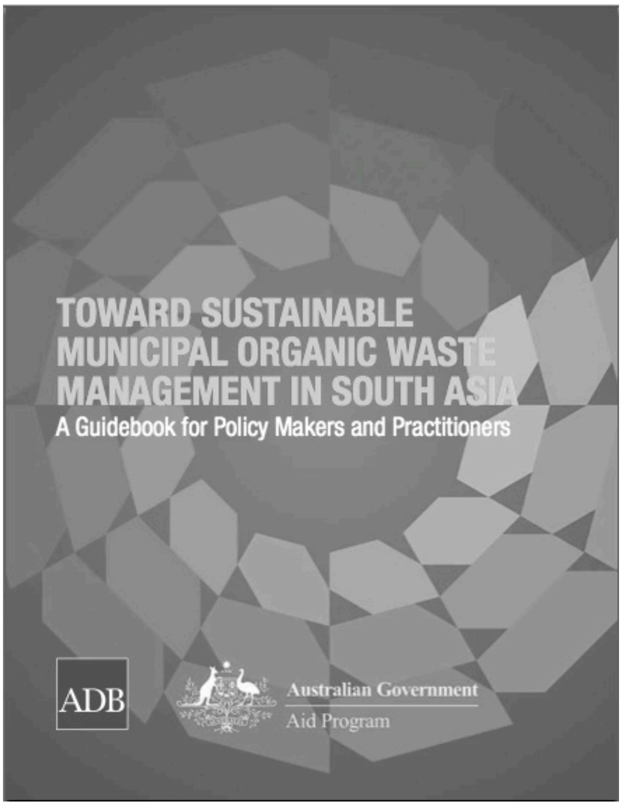

Figure 7.1 Contribution in ADB policy

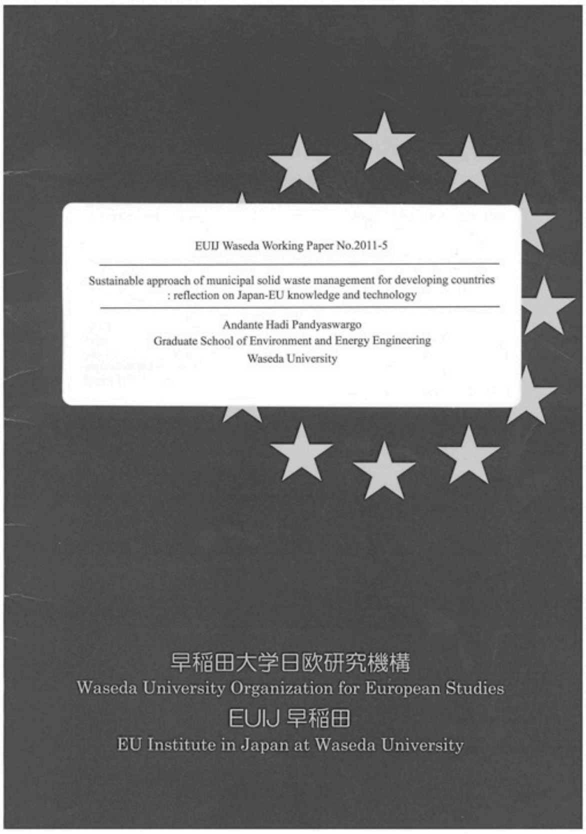

Figure 7.2 EUIJ Working paper Publication

Figure 7.3 Publication in Indonesian magazine: Philantrophy magazine pp.45 - 46

7.2 Future work

Further studies recommended to follow up this study are:

1. A holistic LCA that integrates both Social Life Cycle Assessment (SLCA) and Life Cycle Cost (LCC). This would include the monetization of the social impacts of municipal waste management, and to measure the social impact of MSWM activities. In the developing countries in particular, it is important to consider about the scavengers living nearby the landfill or the disposal site. Health issues such as digestion problems, skin problem, respiratory diseases are among the related diseases caused by improper pollution management in the diposal site. The cost borne by the government or other institution to treat the patients of these diseases caused by the improper waste management should be taken into account for a more accurate life cycle study results.
2. Internalizing the externalities of MSWM including the extended activities such as the transportation of waste from the source, to the temporary disposal site, to the final disposal site, and to the hand of scavengers who collects and sell them to the informal recycling companies. The people who collect the recyclables gathered by the scavengers are often receiving more money than the scavengers themselves. This kind of system is interesting to be analyzed especially if one is thinking to construct the appropriate policy to introduce an Extended Producer Responsibility (EPR) system in the country.
3. Related to the second point, electronic waste, packaging waste, industrial waste, and other forms of commercial goods waste should be address as the immediate future issues that have to be solved. This would also be related to trading of waste with other neighboring countries. The weaker rules a country has regarding this issues, the more prone they would become a dumpsite for other countries.
4. Another issues that can be addressed are the welfare and child rights of the people working in the waste disposal site. Many of the families doing the scavenging jobs are very poor and could not afford sending their children to schools. Even when schools are made free for them, the parents often prefer to

have them working for them to wash the recyclables so that it makes higher values when sold to the recyclable waste collector. Sending child to school means less labor in the house to bring more money. The concept of investment in their children is not an immediate priority for them. Thus a specific education system that is suitable for such families should be developed.

5. Finally, the implementation of policies, law, and scientific results from all the mentioned points should be broken down into tangible, and doable plan. Adjusting plans with the nature and the culture of a nation is often neglected. Plans should be made feasible to the habit of the local citizen. Socialization method good practice in Japan or Europe might be different to those in Indonesia or India. Therefore, cultural aspects should also be considered.

APPENDICES

APPENDIX A

Waseda University
Graduate School of Environment and Energy Engineering
Andante Hadi Pandyaswargo, MEng. MSc.
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Angket weighting kategori Life Cycle Assessment

Weighting kategori LCA yang ada pada saat ini hanya menggunakan standard rata – rata dunia atau negara - negara di Eropa. Angket ini diambil untuk mendapatkan weighting yang lebih akurat yang disesuaikan dengan keadaan lingkungan di Indonesia. Isilah angket ini berdasarkan pengetahuan anda mengenai keadaan lingkungan Indonesia. Kami sangat berterimakasih kepada responden atas partisipasinya.

*Beberapa responden yang dipilih secara acak akan mendapatkan bingkisan dari Jepang (o^_^o)/~ Mohon kirim kembali angket yang sudah diisi ke **andante.hadi@toki.waseda.jp**

Cara pengisian : Mohon klik pada **setiap cell biru muda** untuk memilih score perbandingan tingkat kepentingan masalah lingkungan yang tertera pada kolom **A** terhadap masalah lingkungan pada kolom **B**. Semakin besar angkanya, semakin lebih penting kategori A terhadap B. Penjelasan lebih detail ada di kolom disebelah kanan kotak angket. Abaikan cell abu - abu.

		Kategori	B								
			1	2	3	4	5	6	7	8	9
			Krisis Energi	Pemanasan Global	Penipisan Lapisan Ozon	Hujan Asam	Krisis SDA	Polusi Udara	Polusi Air dan Laut	Masalah Sampah	Perusakan Ekosistem
A	1	1. Krisis Energi	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	2	2. Pemanasan Global	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	3	3. Penipisan Lapisan Ozon	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	4	4. Hujan Asam	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	5	5. Krisis SDA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	6	6. Polusi Udara	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	7	7. Polusi Air dan Laut	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	8	8. Masalah Sampah	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	9	9. Perusakan Ekosistem	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Penjelasan angka pilihan	
9.000	A sangat amat lebih penting
7.000	A sangat lebih penting
5.000	A lebih penting
3.000	A sedikit lebih penting
1.000	A setara pentingnya dengan B
1/3 (0.333)	B sedikit lebih penting
1/5 (0.200)	B lebih penting
1/7 (0.143)	B sangat lebih penting
1/9 (0.111)	B sangat amat lebih penting

List of respondents from ITB (Institut Teknologi Bandung) University surveyed by email

ID	Gender	Status	Major
1	F	S	Biology
2	M	S	Informatics
3	M	S	Mechanical Engineering
4	M	S	Chemical Engineering
5	F	S	Electrical Engineering
6	M	S	Mechanical Engineering
7	M	W	Mechanical Engineering
8	M	S	Civil Engineering
9	F	S	Biology
10	M	W	Mechanical Engineering

F: Female, M: Male, S: Student, W: Working

Averaged answer of respondents from ITB University surveyed by email

9-Impact Category	Category importance
1.Energy depletion	24.51%
2.Global warming	17.00%
3.Ozone depletion	17.99%
4.Acid rain	11.13%
5.Resource consumption	9.23%
6.Air pollution	5.01%
7.Ocean & water pollution	5.01%
8.Problem of waste disposal	4.44%
9.Ecosystem influence	5.67%

List of respondents from ITB University environmental engineering department

	Gender	Status	Major
1	M	S	Environmental Engineering
2	M	S	Environmental Engineering
3	M	S	Environmental Engineering
4	F	S	Environmental Engineering
5	F	S	Environmental Engineering
6	M	S	Environmental Engineering
7	M	S	Environmental Engineering
8	F	S	Environmental Engineering
9	F	S	Environmental Engineering

F: Female, M: Male, S: Student

Averaged answer of respondents from ITB University environmental engineering department

9-Impact Category	Category importance
1.Energy depletion	19.73%
2.Global warming	30.15%
3.Ozone depletion	18.33%
4.Acid rain	11.34%
5.Resource consumption	8.16%
6.Air pollution	4.40%
7.Ocean & water pollution	3.47%
8.Problem of waste disposal	2.85%
9.Ecosystem influence	1.58%

List of respondents from ITB University physics engineering department

No.	Gender	Status	Major
1	M	S	Physics Engineering
2	M	S	Physics Engineering
3	M	S	Physics Engineering
4	F	S	Physics Engineering
5	F	S	Physics Engineering
6	F	S	Physics Engineering
7	M	S	Physics Engineering
8	M	S	Physics Engineering
9	M	S	Physics Engineering
10	M	S	Physics Engineering
11	F	S	Physics Engineering
12	NA	S	Physics Engineering
13	F	S	Physics Engineering
14	M	S	Physics Engineering
15	M	S	Physics Engineering
16	F	S	Physics Engineering
17	M	S	Physics Engineering
18	M	S	Physics Engineering
19	NA	S	Physics Engineering
20	M	S	Physics Engineering
21	M	S	Physics Engineering
22	M	S	Physics Engineering

23	M	S	Physics Engineering
24	M	S	Physics Engineering
25	M	S	Physics Engineering
26	M	S	Physics Engineering
27	F	S	Physics Engineering
28	M	S	Physics Engineering
29	M	S	Physics Engineering
30	F	S	Physics Engineering
31	NA	S	Physics Engineering
32	M	S	Physics Engineering
33	M	S	Physics Engineering
34	M	S	Physics Engineering
35	M	S	Physics Engineering
36	F	S	Physics Engineering
37	M	S	Physics Engineering
38	M	S	Physics Engineering
39	F	S	Physics Engineering
40	NA	NA	NA
41	NA	NA	NA
42	M	S	Physics Engineering
43	M	S	Physics Engineering
44	M	S	Physics Engineering
45	M	S	Physics Engineering
46	M	S	Physics Engineering
47	M	S	Physics Engineering
48	M	S	Physics Engineering
49	M	S	Physics Engineering
50	M	S	Physics Engineering
51	F	S	Physics Engineering
52	M	S	Physics Engineering
53	M	S	Physics Engineering
54	F	S	Physics Engineering
55	M	S	Physics Engineering
56	M	S	Physics Engineering
57	M	S	Physics Engineering
58	M	S	Physics Engineering
59	F	S	Physics Engineering
60	M	S	Physics Engineering

61	M	S	Physics Engineering
62	M	S	Physics Engineering
63	M	S	Physics Engineering
64	M	S	Physics Engineering
65	M	S	Physics Engineering
66	M	S	Physics Engineering
67	M	S	Physics Engineering
68	M	S	Physics Engineering
69	M	S	Physics Engineering
70	F	S	Physics Engineering
71	M	S	Physics Engineering
72	M	S	Physics Engineering
73	F	S	Physics Engineering
74	M	S	Physics Engineering
75	M	S	Physics Engineering
76	M	S	Physics Engineering
77	M	S	Physics Engineering
78	F	S	Physics Engineering
79	M	S	Physics Engineering
80	M	S	Physics Engineering
81	M	S	Physics Engineering
82	M	S	Physics Engineering
83	M	S	Physics Engineering
84	M	S	Physics Engineering
85	M	S	Physics Engineering
86	M	S	Physics Engineering
87	M	S	Physics Engineering
88	M	S	Physics Engineering
89	F	S	Physics Engineering
90	M	S	Physics Engineering
91	M	S	Physics Engineering
92	F	S	Physics Engineering
93	M	S	Physics Engineering
94	M	S	Physics Engineering
95	M	S	Physics Engineering
96	M	S	Physics Engineering
97	F	S	Physics Engineering
98	M	S	Physics Engineering

99	M	S	Physics Engineering
100	M	S	Physics Engineering
101	M	S	Physics Engineering
102	M	S	Physics Engineering
103	M	S	Physics Engineering
104	M	S	Physics Engineering
105	M	S	Physics Engineering
106	M	S	Physics Engineering
107	M	S	Physics Engineering
108	F	S	Physics Engineering
109	M	S	Physics Engineering
110	M	S	Physics Engineering

M: Male, F: Female, S: Student

Averaged answer of respondents from ITB University physics engineering department

9-Impact Category	Category importance
1.Energy depletion	26.92%
2.Global warming	6.03%
3.Ozone depletion	6.03%
4.Acid rain	6.03%
5.Resource consumption	30.16%
6.Air pollution	6.03%
7.Ocean & water pollution	6.38%
8.Problem of waste disposal	6.38%
9.Ecosystem influence	6.03%

List of respondent from Sekolah Alam Cikeas (Eco-school teachers)

No.	Gender	Status	Major	University
1	F	W	Statistics	UNPAD
2	F	W	Agriculture	UNIBRAW
3	M	W	Agriculture	IPB
4	M	W	Biology	ITB
5	F	W	Architecture	IPB
6	M	W	Geology	UNIBRAW
7	M	W	Management	IPB

M: Male, F: Female, W: Working, IPB: Institut Pertanian Bogor, UNIBRAW:Universitas Brawijaya

Averaged answer of respondents from Sekolah Alam Cikeas

9-Impact Category	Category importance
1.Energy depletion	5.61%
2.Global warming	26.97%
3.Ozone depletion	24.78%
4.Acid rain	5.83%
5.Resource consumption	2.60%
6.Air pollution	11.47%
7.Ocean & water pollution	9.51%
8.Problem of waste disposal	9.24%
9.Ecosystem influence	4.00%

List of respondent from Izada (junior high school teachers)

No	Gender	Status	Major	University
1	M	W	Social Science	University of Cape Town
2	M	W	Economics	ISID Gontor
3	M	W	Physics	UNJ
4	F	W	German Literature	UI
5	NA	NA	NA	NA
6	M	W	History	UNJ
7	M	W	Biology	UNJ

M: Male, F: Female, W: Working, UI: University of Indonesia, UNJ: Universitas Negeri Jakarta, ISID: Institut Studi Islam Darussalam

Averaged answer of respondents from Izada

9-Impact Category	Category importance
1.Energy depletion	3.27%
2.Global warming	10.11%
3.Ozone depletion	3.63%
4.Acid rain	1.22%
5.Resource consumption	27.15%
6.Air pollution	12.09%
7.Ocean & water pollution	6.26%
8.Problem of waste disposal	14.59%
9.Ecosystem influence	21.66%

List of respondents from SOU (School of Universe) eco-school teachers

	Gender	Working/Studying	Major
1	M	W	Economics
2	F	W	Biology
3	F	W	Economics
4	F	W	Communication
5	M	W	Economics
6	F	W	Management
7	M	W	Theology
8	F	W	Accounting
9	M	W	Math
10	M	W	Agriculture
11	P	W	Psychology
12	N/A	N/A	N/A
13	M	W	Communication

M: Male, F: Female, W: Working

Averaged answer of respondents from SOU

9-Impact Category	Category importance
1.Energy depletion	3.70%
2.Global warming	4.43%
3.Ozone depletion	3.21%
4.Acid rain	1.45%
5.Resource consumption	2.52%
6.Air pollution	11.22%
7.Ocean & water pollution	18.13%
8.Problem of waste disposal	11.12%
9.Ecosystem influence	44.22%

APPENDIX B

News published from 1 January 2010 to 31
December 2011
Google search done in 14 September 2011

Name of newspaper	Category impact number								
	1	2	3	4	5	6	7	8	9
Tempo Interaktif	64	61	0	12	9	36	85	54	8
Republika Online	22	25	0	2	5	26	28	22	8
Metro TV News	34	23	0	6	6	19	26	21	5
Antara	113	48	0	7	15	12	47	23	17
Media Indonesia	21	33	3	5	12	26	60	29	18
KOMPAS.com	83	83	5	12	24	55	69	74	20
Pikiran Rakyat	3	13	0	0	0	13	18	26	2
Detikcom	77	27	2	0	0	35	26	49	8
Other*	703	499	22	42	93	423	391	782	42
Total	1120	812	32	86	164	645	750	1080	128

*Other media includes: Galamedia, Solopos, Bisnisbali, Samarinda pos, Liputan6, Suara Karya, Inilah.co, Okezone, Kabar Indonesia, Tribunnews, Pos Metro Balikpapan, Berita Indonesia, Surabaya Post, Kaltim post, Harian Equator

Keywords used in Bahasa Indonesia

Category impact number	Keywords
1	Krisis Energi
2	Pemanasan Global
3	Penipisan Lapisan Ozon
4	Hujan Asam
5	Krisis Sumber Daya Alam
6	Polusi Udara
7	Pencemaran air dan laut
8	Masalah Sampah
9	Perusakan Ekosistem

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Category	Author, Title, Publisher, Date of publication
Peer-reviewed paper	○Andante H PANDYASWARGO, Hiroshi ONODA, Katsuya NAGATA, Energy recovery potential and life cycle impact assessment of municipal solid waste management technologies in Asian countries using ELP model, International Journal of Energy and Environmental Engineering 2012, 3:28 DOI: 10.1186/2251-6832-3-28 ○Andante Hadi Pandyaswargo, Sustainable Approach of Municipal Waste Management for Developing Countries: Reflecting on Japan - EU Knowledge and Technology, European Union Institute in Japan (EUIJ) Publication: 2012. 4 ○PANDYASWARGO Andante Hadi, Hiroshi ONODA, Katsuya NAGATA, Integrated LCA for Municipal Solid Waste Management in Developing Country, Design for Innovative Value Towards a Sustainable Society, Proceedings of EcoDesign 2011: 7th International Symposium on Environmentally Conscious Design and Inverse Manufacturing, pp 1100-1105, 2012. ○Pandyaswargo A H, Onoda H, Nagata K, Comparative Analysis of Life Cycle Impact Assessment Methodologies With Application to Indonesian Solid Waste Management Scenarios, Proceedings of The 10th International Conference on EcoBalance: Challenges and Solutions for Sustainable Society, D2-12, 2012.22

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