DISSERTATION

Emergy Analysis for Assessing the Scenarios of Final Waste Treatment in Yogyakarta, Indonesia

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Department of Chemical Engineering and
Environmental Technology
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submitted for the degree of
Doctor of Engineering Science (Dr.techn)

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STATUTORY DECLARATION

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

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Abstract

The main objective of this PhD study was to evaluate the influence of different legal frame conditions on environmental parameters of two different kinds of solid waste treatment. Therefore, the global warming potential (GWP) and the emergy values for landfill and composting was calculated and compared.

Because of capacity reasons in Yogyakarta, Indonesia it will be necessary to construct a new landfill with a disposal rate of about 140,000 t/yr. In this study, 3 alternatives (scenarios) for the operation of this new landfill in respect to the above mentioned environmental parameters are described. For reasons of comparison, in scenario 0 the new landfill was operated equally to the old landfill (Bendo site). In Scenario 1, operation according local law (City Ordinance No 18/2002) and in Scenario 2, operation according national law (The Waste Law no. 18/2008) is assumed .

In a field survey at Bendo landfill waste reduction by scavengers who sorted recyclable materials such as plastic, paper, glass and metal was observed for each material at a rate of 7.54%, 12.87%, 0.15% and 0.03%. This rate was applied for scenario 0 and scenario 1.

The calculation of GWP for the new landfill delivered the highest result from Scenario 0 at a level of 2.78 Million ton CO_2e and the lowest result from Scenario 2 at a level of 2 Million ton CO_2e which is a reduction of 28% compared to Scenario 0 (base scenario). Furthermore, the emergy analysis indicated that treatment in landfill required the largest emergy input for all scenarios with the percentage between 92% and 97%. Scenario 0 contains the lowest total solar emergy implying that it required lower emergy input compared to other scenarios. Scenario 1 needed the least emergy investment. Meanwhile, Scenario 2 offered the highest emergy recovery contributed mainly by the output from higher scavenging rate and composting rate. The calculation of emergy indices result in the best alternative is Scenario 2 since it has more environmental parameters with the value that meets the criteria. However, the result implied that none of the scenarios is capable to save the greatest specific emergy since all scenarios had the negative value for the net emergy. The much more emergy input than the emergy output caused the enormous unbalance between benefit and cost

Keywords: municipal solid waste management, landfill scenario, methane emission, emergy analysis

Zusammenfassung

Das Hauptziel dieser Dissertation war die passende abschließende Abfallbehandlung entsprechend den lokalen Potenzialen und den Herausforderungen, die innerhalb des Untersuchungsbereiches vorhanden sind, festzustellen. Die Studie stellte Alternativen für die lokale Regierung zur Verfügung, um die beste Lösung für die zukünftige kontrollierte Mülldeponie in Yogyakarta, Indonesien zu entscheiden, wegen dem Gesetz Nr. 18/2008. Das Gesetz verpflichtet die lokale Regierung die umweltvertragliche Abfallbehandlung durchzuführen. Drei Szenarien wurden untersucht und drei verschiedene Grundprinzipien liegen jedem Szenario zugrunde

1) Szenario 0 wegen der aktuellen verbleibenden Abfallwirtschaftszustände
2) Szenario 1 wegen der Ziele des städtischen Abfallmanagements;
3) Szenario 2 wegen dem 22. Artikel des Gesetzes Nr. 18/2008.

Das Treibhauspotential und die Emergy Werte wurden für die Auswertung der Szenarien berechnet.

Eine Untersuchung vor Ort an der Bendo Mülldeponie ergab, dass die Recyclerate von Plastik, Papier, Glass und Metall jeweils 7.54%, 12.87%, 0.15% and 0.03% beträgt. Diese Werte wurden für Szenario 1 und Szenario 2 angewandt.

Die Berechnung der Methanemission zeigte, dass das Szenario 0 das höchste GWP (2.78 Mio t CO_2e) und das Szenarios 2 das niedrigste GWP (2 Mio t CO_2e) hat. Die Emergy Analyse zeigte darüber hinaus, dass die Abfallbehandlung in der Mülldeponie den größten Emergaufwand für alle Szenarien mit dem Prozentsatz zwischen 92% und 97% erfordert. Das Szenario 0 enthält das niedrigste Gesamtsolaremergy. Es bedeutet, dass Szenario 0 im Vergleich zu anderen Szenarien einen geringeren Emergyaufwand erfordert. Szenario 1 benötigte die geringste gesamte Emergyinvestition. Szenario 2 hat die höchste Emergyrückgewinnung, die hauptsächlich auf den Output der höheren Sortierungsrate und Compostierungsrate zurückzuführen ist. Die Berechnung von Emergyindizes ergaben die besten Werte für Szenario 2. Das Ergebnis zeigte allerdings, dass keines der Szenarien fähig ist, die größte spezifische Emergy zu speichern, weil alle Szenarien einen negativen Wert für die Nettoemergy aufwiesen. Der viel größere Emergyaufwand als der Emergyoutput verursachte die enorme Unausgeglichenheit zwischen Nutzen und Kosten.

Schlüsselwörter: städtisches Abfallmanagement, Mülldeponie Szenarien, Methanemission, Emergy Analyse

Contents

Abbreviation

ASEAN	: Association of South East Asian Nation
ASEP	: ASEAN Sub-regional Environmental Programs
CDM	: Clean Development Mechanism
CER	: Certified emission reduction
DOC	: Degradable Organic carbon
$DDOC_m$	: mass of decomposable DOC deposited
ELR	: Environmental Loading Ratio
ESI	: Emergy Sustainability Index
EU	: European Union
EYR	: Emergy Yield Ratio
GHG	: Green house gas
GWP	: Global warming potential
IPCC	: The Intergovernmental Panel on Climate Change
LFG	: Landfill gas
LHV	: Low heating value
LoS	: Level of Service
MCF	: Methane Emission Factor
MDGs	: Millenium Development Goals
MSWM	: Municipal solid waste management
NMOCs	: Non-Methane Organic Compounds
O&M	: Operation & Maintenance
PROPER	: Program for Pollution Control. Evaluation and Rating
SWDS	: Solid waste disposal site
SWM	: Solid waste management
UNEP	: United Nation of Environmental Program
WtE	: Waste-to-Energy
WWTP	: Waste water treatment plant

1. Introduction

Worldwide, the waste management sector contributes approximately 3 – 5 % of total anthropogenic emission in 2005 (Bogner, J. et.al., 2007). Compared to the total emission, this percentage is relative minor. Yet, the waste sector is in a state that it moves from being a minor source of global emissions to becoming a major saver of emissions (UNEP, 2010). Emission reduction from waste sector can be achieved through waste hierarchy principles including disposal as the least preferred option for managing waste and avoidance and minimization as the most preferred option waste. The implementation of these waste managements can reduce emissions from other sectors of the economy such as energy, forestry, agriculture, mining, transport, and manufacture. The emission from waste sector is mainly sourced from landfill through methane emission which is produced during waste degradation process (Bogner, J. et.al., 2007). Landfill has been practiced for disposing the waste in developed and developing countries with different level of technical and safety requirements. In developed countries such as EU member states, sanitary landfill is common to be practiced and there is decreasing trend of landfilling for the EU Landfill Directive requiring the reduction of biodegradable waste disposal in landfill (EEA, 2007). Mean while, developing countries prefer to operate controlled landfill though continuous efforts to promote other waste disposal methods such us recycling, incineration, mechanical and biological treatment.. There is an increasing trend of emission from landfill globally although in European Union (EU), the emission has decreased during the last 20 years due to the increasing rates of landfill CH_4 recovery in many EU member states and decreasing rates of landfilling in the EU. The reason for this is that the emission from landfill in developing countries, are expected to increase concurrently with increased landfilling (UNEP; 2010). Unfortunately, many developing countries operate an open dump site instead of a controlled landfill. Open dumping method creates environmental damage. It takes up not only more and more valuable land space, but also causes air, water and soil pollution, discharging carbon dioxide (CO_2), methane (CH_4) and other gases into the atmosphere and chemicals into the earth and groundwater which can threaten human health, plants and animals.

The practice of open dumping method is quite common in Indonesia. Almost 90% of landfills in Indonesia are open dump sites (MoE, 2008[a]). The minor financial viability of the local governments is the reason why they are not be able to operate a proper solid waste disposal site (SWDS) (Susmono, 2009[a]). The waste disposal in open dump site contributes the major greenhouse gas (GHG) from waste sector. At national scale, emission from waste sector is less compared to other sectors. It amounts to 166.8 Mt CO_2e or 8% of the total national GHG emission which was 1,991 Mt CO_2e in 2005. The main contributing sectors were Land Use Change and Forestry (40%) and followed by energy (47%) (MoE, 2010). Though its small contribution to the total national GHG emission, the emission from waste sector even contributes to the total GHG emission which makes Indonesia belongs to the tenth largest emitter in the world. This fact forces the government to commit the 26% reduction of the total GHG emission by 2020 from 2009 level which is amounted to 2,042 Mt CO_2e (MoE, 2010). This commitment should be supported by adequate legal framework in related sectors including waste sector. In waste sector, there was no law in national level regulating waste management until 2008. The absence of waste law in national level and the lack of laws controlling municipal waste management in regional level is one of some reasons for poor landfill condition (Bengtsson, 2008; Meidiana, 2010[a]). Based on the data in 2006, the total domestic waste generation in Indonesia was about 38.5 million tons. Most of this waste ended up in landfill sites that were operated as an open dump site rather than sanitary landfill and only a little fraction of the collected waste was treated through recycling, composting or incinerating. Additionally, about 60% of total landfills (179 sites) operated by local government close to the enclosure (less than 5 years), but only 47% of them has been decided to be closed and replaced by the new final disposal site (MoE, 2008[a]). Open dumping practices in many Indonesian cities lead to environmental problems such as surface and ground water pollution, emission of GHG, and odor nuisance. Therefore, The Waste Law No. 18/2008 is not only an opportunity, but also a challenge for the local governments to provide the community with better waste management. The enactment of the law gives them a wider role to administer the waste management and the implementation of environmentally sound waste treatment.

The enactment of The Waste Law no. 18/2008 obliges the local governments in Indonesia to implement environmentally sound waste management practices including a safe final disposal site. Article 22 defines this clearly by intending the implementation of environmentally friendly technology for final waste treatment, whereas Article 44 intends the requirement of safe landfill practices (MoE, 2008[b]). Local government of Yogyakarta as waste authority and landfill operator is also required to meet this law. The municipality will close the old landfill (*Bendo landfill*) in 2012 and construct a new landfill in a new site not so far from the old landfill. Exerting full implementation of the Waste Management Law 18/2008 by constructing a sanitary landfill for environmentally sound landfill is not necessarily suitable for the inferior waste management conditions in Yogyakarta such as subordinate infrastructure, financial stringency, and insufficient technology. A controlled landfill is appropriate for the new landfill for some local conditions (Meidiana, 2011). In controlled landfill, scavenging activity is allowed and believed as a contribution to waste reduction. In developing country, scavenging can provide economic and environmental benefits, and societal benefits (Medina, 1997; Rankokwane, B., 2006). The old landfill in Yogyakarta involves scavengers to sort the saleable material such as plastic, paper, metal and glass. Scavenging is becoming a main income for most scavengers and can contribute to waste reduction. However, there are discussions among local decision makers about the involvement of scavengers in the new landfill. Some believe that reducing the waste by treating it as near as possible to the waste source is more effective than allowing the scavengers to sort the waste at the landfill. Therefore, the more comprehensive analysis is required to measure precisely the effectiveness of waste reduction through scavenger.

Composting is another waste treatment method which has been applied in Yogyakarta since 2005. The organic waste from household is processed in community based composting centers involving about 15,000 households. Along with waste sorting, composting can have a significant contribution in reducing waste delivered to landfill. However, an implementation of such centralized composting centers adjacent to the new landfill should be observed since it requires a high investment. Improving the existing composting center capacity may be more efficient than constructing a new big capacity composting center to reduce waste disposal in landfill which can prolong the landfill age and decrease landfill gas (LFG) emission at the new landfill.

The comparison study of waste management policy between European Union (EU) and Association of South East Nations (ASEAN) as well as between Austria and Indonesia is provided also in this study. The discussion objects to provide comprehensive perspective about the role of waste policy in regional scope in waste management practices in national scope. It can be a lesson for Indonesia since Austria belongs to the country with the highest material recovery rates in EU (EEA, 2007). Furthermore, the change in national waste management practice more or less will affect the one in local level, including Yogyakarta City. Considering the potentials and the challenges in the area of study, the PhD study aims to analyze the cost and benefit in form of global warming potential (GWP) and emergy for any possible final waste treatment methods in the area of study. The evaluation of the current conditions including the old landfill performance, the available legal frameworks, the financial capability, the natural features and the social backgrounds was conducted. The result is used to determine the scenarios appropriate for the dynamics of waste sector in Yogyakarta City. Therefore, different scenarios for the new landfill are proposed in this study based on the local situation in Yogyakarta. The selection of the best scenario is determined through the environmental parameters including the global warming potential and the emergy indices. The result of the study can be used as a reference for the local decision maker to determine the suitable final waste treatment in Yogyakarta City.

2. Research Outlines

The dissertation aims to analyze the scenarios for the final waste treatment in Yogyakarta, Indonesia. The proposed scenarios are assessed based on global warming potential using IPCC Tier 2 method and sustainability as well as efficiency using emergy analysis. By assessing these scenarios, it is possible to determine the best choice for appropriate final waste treatment. Considering the general current local conditions of waste management, the study is conducted with the focus on the problems and the goals highlighted in the following sub chapters.

2.1. Problem Statement

- The new landfill have to meet the Waste Law No. 18/2008 requiring safe final waste treatment method
- Requirements to shift from open dumping methods to other environmentally sound final waste treatment method
- Inferior condition of waste management especially landfill

In order to solve the above research problems, the study with the title of **Emergy Analysis for Assessing the Scenarios of Final Waste Treatment in Yogyakarta, Indonesia** focuses on the objectives explained in sub chapter 2.2.

2.2. Objectives

- To evaluate current municipal waste management situation in Yogyakarta
- To estimate methane emission from the old landfill
- To predict methane emission from the new landfill
- To determine the appropriate scenarios based on the local conditions
- To investigate the multiple scenarios and to evaluate them in terms of environmental assessment.

The environmental assessment in this PhD study includes the global warming potential and the emergy indices. The steps done in the research are described in Figure 1.

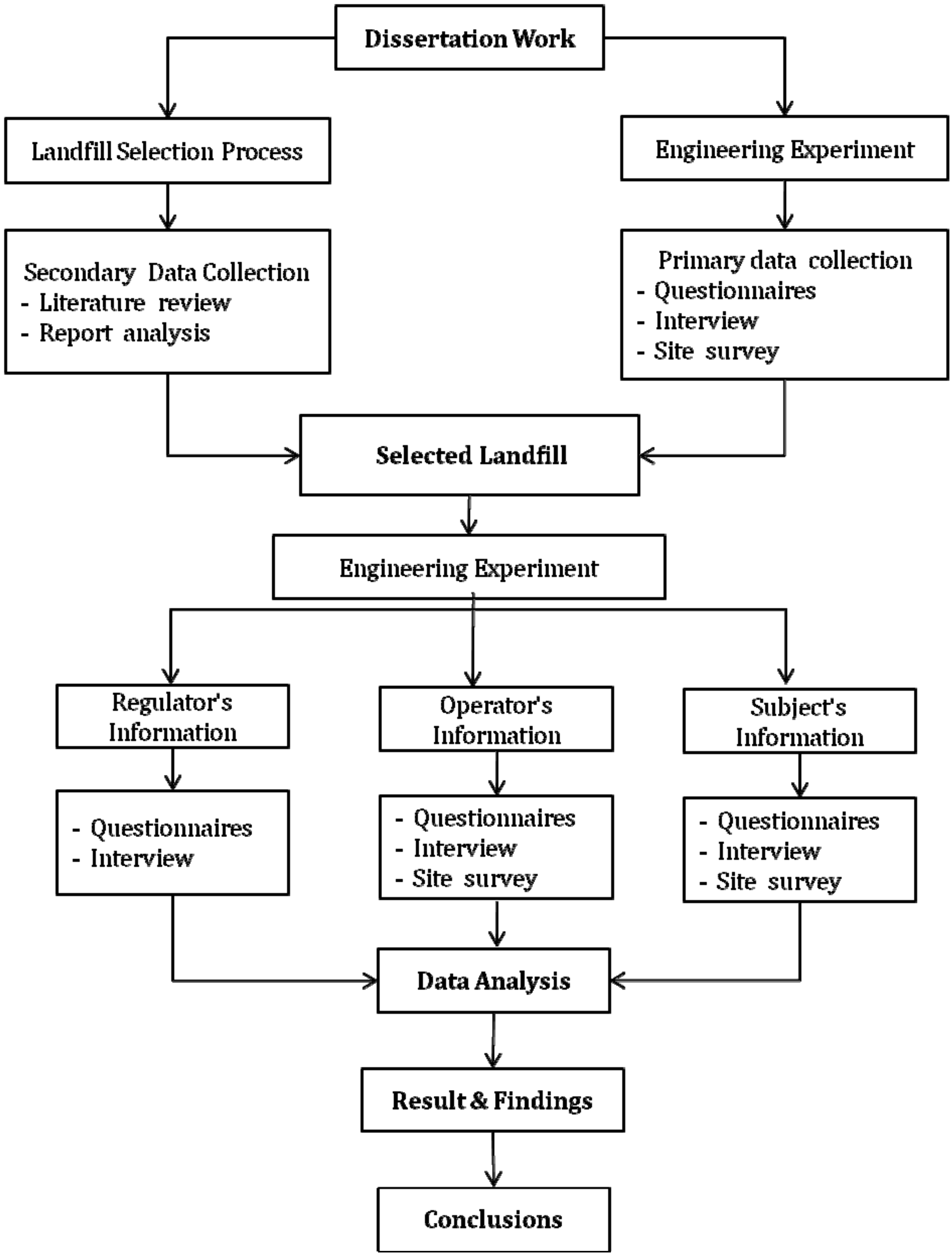


Figure 1. Research outline

Prior to the process of the research, a preliminary study has been conducted in order to select the area of study. The data collected from primary and secondary surveys are compared and presented in the previous work (Meidiana, 2011). The result implies that Yogyakarta is the proper case for the research for better available data related to the waste management.

The dissertation is presented in some chapters. Chapter 1 provides information about the motivation and the necessity of the research. Chapter 2 presents the scope of the works and the research questions. A schematic diagram is provided also to give the overview of the work. Chapter 3 provides background information about waste characteristic, waste degradation process in landfill and its implication to the environment and waste treatment. The concept of the emergy analysis has been also described in this chapter. Chapter 4 presents the policy of waste management in developed and developing country. The comparison between European Union (EU) and Association of South East Asian Nation (ASEAN) as well as between Austria (developed country) and Indonesia (developing country) is made to give a perspective about the influence of the policy on waste management practices in regional and national level. The actual situation of the waste management in Indonesia is also presented in this chapter. Chapter 5 provides the methodology used in the research including the steps to select the scenario, the calculation of global warming potential using IPCC Tier 2 method and the calculation of emergy values and emergy indices. Some assumptions and limitations are also presented due to the lack of input data. The analysis and the result of the research are presented in Chapter 6. Finally, the concluding remarks and recommendations are presented at the end of the dissertation.

3. Theoretical framework

3.1. Green House Gas Emission from Waste

The municipal solid waste management (MSWM) in urban system includes collection, transportation, treatment, and disposal. All the involved activities in MSWM produce green house gas (GHG) emission as the source of GHG from waste sector with the varying levels. At the disposal step, MSWM is usually delivered to the landfill as the final solid waste disposal site (SWDS). The landfill emits GHG which are methane (CH_4), carbon dioxide (CO_2), non-methane volatile organic compounds (NMVOCs), Nitrous oxide (N_2O), and other trace gases generated during the process of waste degradation. The other product from waste degradation process in landfill is leachate. The landfill gas (LFG) is mainly comprised of methane (about 50-60%) and carbon dioxide (about 30-40%). The presence of methane and carbon dioxide in the atmosphere contribute to global warming and climate change (UNEP, 2010). Methane has global warming potential (GWP) 21 times higher than carbon dioxide (IPCC, 1996). According to Forster et. al., (2007), the GWP of methane is 25 times higher than carbon dioxide when a time horizon of 100 years is considered. Methane from landfill is the largest source in waste sector although waste sector contribute only a small amount to the global greenhouse gas (GHG) emissions (<5%) with total emissions of approximately 1300 $MtCO_2eq$ in 2005 (Bogner, J. et.al., 2007). The second largest source is waste water treatment plant (WWTP) (UNEP, 2010). The other main sources of methane from waste sector are aerobic composting plant and anaerobic digestion system. In developed country, the methane emission from waste sector is predicted to remain relatively stable due to the diversion of waste from landfilling and recovery of landfill gas (LFG). On the contrary, the methane emission from waste sector in developing country increases because of growth in population and prosperity and improvement of waste collection system (Monni et. al, 2006). GHG emission mitigation can be done through many appropriate low-to-high technology strategies. For example, landfilling with gas recovery system to reduce methane emission, post-consumer recycling to avoid waste generation, composting of selected waste fractions to avoid GHG generation, and processes that reduce GHG generation compared to landfilling (thermal processes including incineration and industrial co-combustion, MBT with landfilling of residuals, and anaerobic digestion). The choice of the method should be relies on local, regional and national conditions for both waste management and GHG mitigation (UNEP, 2010).

3.2. Waste degradation process in landfill.

Landfill is the final step in solid waste management and receives the waste from all sources such as households, commercials, and industries. The waste contains organic substances such as food, paper, wood, and yard waste. The waste degrades as it is dumped in landfill and starts to decompose as microbes begin to consume the carbon in organic material. The degradation process of organic substances under anaerobic conditions generates LFG comprising methane (approximately 50%), carbon dioxide (approximately 50%), and other gaseous compounds (< 1%). Besides LFG, landfill emits also leachate. LFG and leachate have a potential to influence the environmental adversely. Degradation process in landfill is driven by external factors such as atmospheric pressure and temperature and internal factors such as waste characterization and soil properties which influence the landfill properties (UNEP, 2010).

The evolution rate and the quantity of the gas from the landfill are dependent on some factors, such as; (a) waste composition, (b) age of waste, (c) presence of oxygen, (d) moisture content, (e) temperature, (f) site management (Crawford and Smith, 1985). Waste composition influences the methane production since the bacteria activity level and bacterial decomposition degree depend on the waste composition. If there is adequate nutrient in waste, these bacteria will decompose waste better so that the landfill gas production increases. The mode of decomposing is determined by the presence of the oxygen. The more oxygen presents in a landfill, the longer aerobic bacteria can decompose waste during the first phase of the decomposition. Bacteria will begin to produce methane if oxygen is used up. After this stage, the waste decomposition will be an anaerobic process. The anaerobic decomposition of solid waste can be described in the following generalized chemical reaction (Equation 1.) (Tchobanoglous et al., 1993):

$$Organic\,matter + H_2O \xrightarrow{Bacteria} Bio\deg raded + CH_4 + CO_2 + Othergases \qquad (1)$$

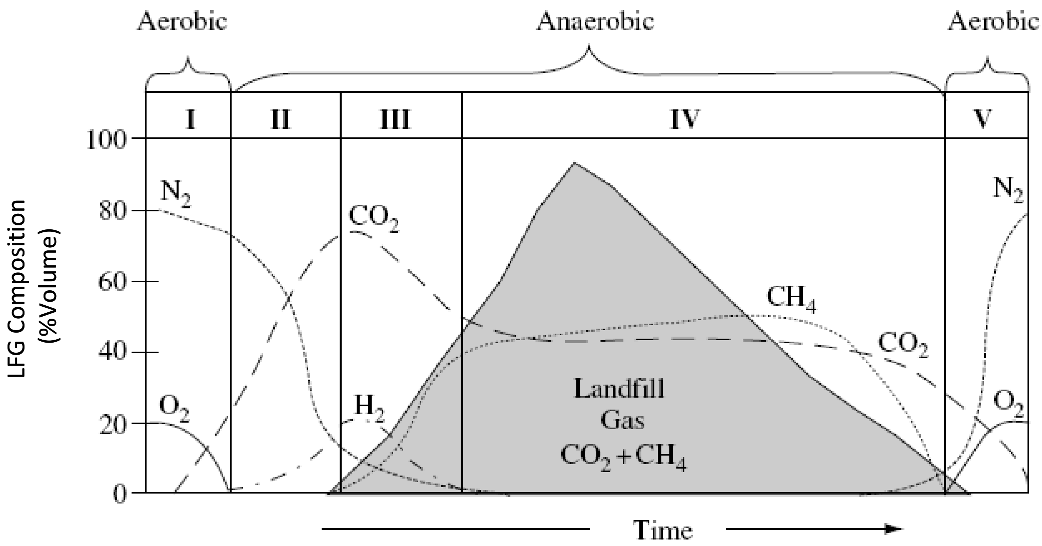
The landfill gas (LFG) production will rise if the moisture content in a landfill increases, since the moisture encourages the bacterial growth and transports nutrient and bacteria to all areas within a landfill. The temperature can influence gas production, but generally warm temperature will increase bacterial activities leading to higher gas production.

The age of refuses is also an important factor. Landfill usually produce appreciable amount of gas within 1 to 3 years. Gas will be produced at highest rate in 6-7 years after wastes are dumped and within the next 20 years, almost all of gas still be produced until it starts to decrease to small quantity for more 50 years or more (Crawford and Smith, 1985).

There are some methods to calculate the LFG rate in landfill. However, the LFG rate is mostly calculated from decomposable fraction of waste. Equation 2 can be used to estimate the total volume of potentially generated LFG under assumption that decomposable organic waste convert completely to CO_2 and CH_4 (Tchobanoglous et al., 1993).

$$C_aH_bO_cN_dS_e + \left(\frac{4a-b-2c+3d+2e}{4}\right)H_2O \rightarrow \left(\frac{4a+b-2c-3d-2e}{8}\right)CH_4 + \left(\frac{4a-b+2c+3d+2e}{8}\right)CO_2 + dNH_3 + eH_2S \quad (2)$$

Waste is disposed of in landfill not only for a short period, but some times for many years. Therefore, decomposition of waste in a landfill may occur in several phases depends on the age of the waste. This means that the waste in one area may experience a different phase of decomposition compared to another area within the landfill. There are four distinct phases during stabilization process of waste in landfill. The first phase is the aerobic phase and the rest are anaerobic phases comprises of three stages with three distinct physiological groups of micro-organisms. Stage 1 involves the fermentative bacteria, which include anaerobic and facultative micro-organisms. Stage 2 involves acetogenic bacteria and stage 3 utilizes two distinct types of methanogenic bacteria. Figure 2 describes the typical landfill gas production pattern in a landfill (Tchobanoglous, 2002).



Source: Tchobanoglous, 2002

Figure 2. Waste degradation process in landfill

The aerobic phase is associated with initial placement of solid waste and accumulation of moisture within the landfill. In this phase, the aerobic decomposition is occurred caused by the aerobic bacteria that consume oxygen while breaking down the long molecular chains of complex carbohydrates, proteins, and lipids that comprise organic waste. The amount of carbon dioxide increases because it is the byproduct of this process, while nitrogen declines. Phase 1 continues until available oxygen is used up and the process can last for days or months, depending on how much oxygen is present when the waste is disposed of in the landfill. As the oxygen in landfill is depleted, phase 2 which is anaerobic process starts. Compounds created by aerobic bacteria are converted into acetic, lactic, and formic acids and alcohols by anaerobic bacteria. The landfill becomes highly acidic as pH value decreases. Gaseous carbon dioxide and hydrogen is produced during this process. Phase 3 or methane fermentation phase begins when certain kinds of anaerobic bacteria consume organic acids produced in the phase 2 and acetate is formed. This process causes the landfill to become a more neutral environment. In this phase, methane-producing bacteria begin to establish themselves. Methanogenic and acid-producing bacteria have a symbiotic relationship. Acid-producing bacteria create compounds for the methanogenic bacteria to consume, while methanogenic bacteria consume the carbon dioxide and acetate. If carbon dioxide and acetate is too much, it would be toxic to the acid-producing bacteria. In the next phase, the composition and production rates of landfill gas remain relatively constant. The LFG usually contains mainly 45 percent to 60 percent methane by volum and 40 percent to 60 percent carbon dioxide. Some small fractions of other gases can also potentially be formed. The quantities of the gas produced in landfill depend on the biodegradable fraction of waste, the presence of microorganism and suitable aerobic and anaerobic conditions, and moisture. After phase 4, LFG production drops off and is negligible because all the readily bio-degradable waste has been converted to methane (CH_4) and Carbon dioxide (CO_2).

The waste composition affects the composition of GHG since each component of waste generates varied gas composition as it decompose as described in Table 1 and Table 2

Table 1. The main composition of the landfill gas

Component	Units	% by Volume	Characteristic
Methane	%	45 – 60	Colorless, odorless, soluble in water, lighter than air. Explosive (concentration from 5% - 15% by volume of air)
Carbon dioxide	%	40 – 60	Small concentrations in the atmosphere (0.03%). Non combustible, Colorless, odorless.

Oxygen	%	0.1 – 1	Colorless, odorless. About 21% of the atmosphere. Slightly soluble in water, heavier than air
Nitrogen	%	2 – 5	About 79% of the atmosphere. Odorless, tasteless, and colorless.
NMOCs (Non methane organic compounds)	%	0.01 – 0.06	
Ammonia	%	0.1 – 1	Colorless gas with a strong odor
Sulfides	%	0 – 1	Cause unpleasant odors even at very low concentrations.
Hydrogen	%	0 – 0.2	odorless, colorless gas
Carbon monoxide	%	0 – 0.2	Odorless, colorless gas.

Source: (Tchobanoglous, et. al.1993; EPA 1995; Cheremisinoff, 2003)

The major constituents of LFG are CH_4 and CO_2 which are odorless, whereas the minor components are hydrogen, carbon monoxide, sulfides and ammonia. Landfill gas contains components which are flammable and when mixed with the air can reach explosive concentration in confined space. Some of the trace gas in landfill can have a toxic effect in high enough concentration, for example hydrogen sulfide. Methane and carbon dioxide are greenhouse gases causing global warming.

Table 2. Gas composition from varied components of waste

Component	Total CH4 and CO2 [m3/ton]	Gas composition %	
		CO2	CH4
Cellulose (Carbohydrate)	829	50.0	50.0
Protein	988	48.5	51.5
Fat	1430	28.6	71.4
Typical waste	300 – 500 (estimated)		
Typical waste	39 - 390 (measured)		

Source: (Mc Bean et al., 1995)

Estimation of the theoretical production of the gas from typical waste indicates that 300-500 m³ gas will be generated per 1 ton waste dumped in landfill through lifetime of the site. However, from the actual measurement, there is a high range between 39 and 390 m³ methane per ton waste produced during the landfill operation. This is due to the fact that not all waste is decomposed (Mc Bean et al., 1995).

3.4. Estimation of landfill gas generation

The Intergovernmental Panel on Climate Change (IPCC) was founded by the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO) in 1988. The main objective of the IPCC is to assess scientific, technical and socio-economic information relevant to the understanding of human induced climate change, potential impacts of climate change and options for mitigation and adaptation. In 2006, the panel has produced The 2006 IPCC Guidelines for National Greenhouse Gas Inventories as an answer for UNFCCC´s invitation to update the Revised 1996 Guidelines providing the countries the internationally methodologies for intended use in estimating greenhouse gas inventories, which should be reported to the UNFCCC.

The IPCC proposed 3 methods to estimate CH_4 emission which are IPCC Tier 1 method, Tier 2 method and Tier 3 method. IPCC Tier 1 method is a mass balance method using default values from IPCC for the parameters. The Tier 1 is the simplest method compared to other higher Tiers method and appropriate for the conditions with no adequate data. Tier 2 and Tier 3 are based on the Fist Order Decay (FOD) method which assumes that the degradable organic carbon (DOC) in waste decomposes slowly during the period in which methane and carbon dioxide are formed. If conditions are constant, the rate of CH_4 production depends solely on the amount of carbon remaining in the waste. As a result, emissions of CH_4 from waste deposited in a disposal site are highest in the first few years after deposition, and then gradually decline as the degradable carbon in the waste is consumed by the bacteria responsible for the decay. Tier 2 and 3 methods are appropriate where quite good quality data are available. However, specific activity data and historical waste disposal at solid waste disposal site is required for calculation with Tier 2. If there is a lack of required data, the use of some default parameters is allowed (IPCC, 2001; IPCC, 2006). Meanwhile, Tier 3 method requires good quality activity data. It is a FOD method with nationally developed key parameters or measurement parameter derived from country specific parameters. Tier 2 method is used in the study and Table 3 describes the default parameters using in the calculation.

Table 3. Selected default value for IPCC Tier 2 calculation

Parameters	Default values	Remarks
Methane correction factor (MCF)	0.8	Type of site : unmanaged shallow (>5 meter waste)
Fraction of CH_4 in generated LFG (F)	0.5	Most waste in solid waste disposal site generates a gas with about 50% CH4. Though the available default value, the value from the calculation is used.
Fraction of degradable organic carbon (DOC)	Depend on waste type	Ranges between 0.15 – 0.40
Fraction of degradation Organic Carbon with Decomposes (DOC_f)	0.5	
Oxidation factor (Ox) with	0	Unmanaged SWDS or managed but not

CH_4 oxidizing material i.e. soil, compost		covered with aerated material
Waste decay rate (k)	Depend on waste type	Ranges between 0.17 - 0.7*
Methane recovery (R)	0	CH4 recovery should be reported only when references documenting the amount of CH4 recovery are available
*estimated based on Jensen and Pipatti) where: - Tropical, Mean Annual Temperature (MAT) 20 C - Moist and wet, Mean Annual Precipitation (MAP) 1000 mm - Rapidly degrading waste (food waste)		

Source: (IPCC, 2006)

Methane generation is a function of methane correction factor (MCF), fraction of methane in LFG (F), fraction of dissimilated degradable organic carbon (DOC_f), fraction of degradable organic carbon (DOC), methane recovery (R) and waste decay rate (k).

Methane correction factor (MCF) reflects the way waste is managed and the effect of site structure and management practices on methane generation (IPCC, 2006). MCF is applied because there are varieties of control, waste placement and site management in waste disposal leading to varieties of methane generation in SWDS. Unmanaged SWDS produce less methane than anaerobic managed SWDS since a larger fraction of waste decomposes aerobically in the top layer. In an unmanaged SWDS with deep disposal and/or with high water table, the fraction of waste that degrades anaerobically should be greater than in shallow SWDS. The value of MCF is specific to that area and should be interpreted as the waste management correction factor that reflects the management aspect it encompasses. During degradation process, methane is generated. The fraction of methane in LFG is approximately 50%. The fraction can be calculated using chemical reaction of anaerobic solid waste decomposition or measured from the field. The suggested default value is 0.5 but the applied value in this study is calculated from the chemical reaction.

Degradable organic carbon (DOC) is the organic carbon in waste that is accessible to biochemical decomposition. The DOC in bulk waste is estimated based on the composition of waste and can be calculated from a weighted average of the degradable carbon content of various components (waste type) of the waste stream. Degradable organic carbon which decomposes (DOC_f) is a variable that indicates the estimation of the fraction of carbon that is ultimately degraded and released from SWDS. The value reflects the fact that some degradable organic carbon does not degrade, or degrades very slowly, under anaerobic conditions in the SWDS. DOC_f value is dependent on many factors like temperature, moisture, pH, composition of waste, etc. However, if there is no measurement for DOC_f the recommended default value is 0.5.

The waste decay rate value or k value is a function of some factors such as moisture, pH, temperature, and other environmental factors including landfill operating conditions (EPA, 1991). The high waste decay rate value is associated with high moisture conditions and rapidly degradable materials, i.e. food waste. The low k value indicates the slow decay rate which is associated with dry site conditions and slowly degradable waste such as wood and certain paper. The k value for inert material is zero as it is not be degraded. Since there is no measurement at labor scale, the default value for k is used in the study. Table 4 shows the default value of k and DOC for wet tropical climate.

The oxidation factor (OX) indicates the amount of methane from SWDS oxidized in the soil or other material covering the waste. The value for methane recovery (R) is considered if the generated methane is recovered and combusted in a flare or energy devices. However, the methane recovery is reported only when references documenting the amount of methane recovery are available (IPCC, 2006). Methane emitted from landfill is calculated based on the methane generation without neglecting the factors of methane recovery and oxidation. Hence, the methane actually emitted from the landfill will be smaller than the amount generated if the covering and recovery system exist in landfill. The variable of methane recovery (R) and/or oxidation factor (OX) is vanished for an unmanaged SWDS or a managed SWDS without adequate soil covering because none of the methane generated is oxidized and/or recovered. Thus, the methane emitted is equal to methane generated in landfill.

Table 4. Decay rate (k) value and degradable organic carbon (DOC)

Type of Waste	Component	DOC %	k value for wet tropical climate	
			default	range
Slowly degrading waste	paper/textile waste wood/straw waste	40 30	0,07 0,035	0,06 - 0,085 0,03 - 0,050
Moderately degrading waste	other (non-food) organic putrescible/garden /park waste	17 17	0,170	0,15 - 0,20
Rapidly degrading waste	food waste/sewage sludge	15	0,4	0,17-0,7

Source: (IPCC, 2006)

Using the FOD method, CH_4 generation potential (Lo) of the waste disposed of in a certain year will decrease gradually throughout the following decades. Methane generation potential is a product of mass of decomposable DOC deposited, methane concentration in LFG, and the molecular weight ratio of methane and carbon (CH_4/C). Once the annual methane generation is calculated, the total methane generation through landfill lifetime can be calculated.

Waste properties can be analyzed using proximate and ultimate analysis. Proximate analysis includes an assessment of the levels of moisture, volatile, fixed carbon and ash, whereas ultimate analysis of municipal waste component involves determination of carbon, hydrogen, oxygen, nitrogen, and sulfur (C, H, O, N, S) content. The ultimate analysis can be used to determine the composite molecular formula of the waste component. Since there is no lab-scale measurements, typical value for the parameters in both analysis were used. Table 5 and Table 6 show the typical value for parameters used in proximate analysis and ultimate analysis of solid waste respectively, suggested by Kaiser (1978). Another important waste property to be analyzed is caloric value. The caloric value measurement of solid waste is required if the waste is purposed to be used in Waste-to-Energy (WtE) plant.

Table 5. Typical value for the proximate analysis

Component	Moisture	Volatile	Fixed carbon	Ash
Paper/paper products [% by weight]				
paper mixed	10,24	75,49	8,44	5,38
newsprint	5,97	81,12	11,48	1,43
corrugated boxes	5,20	77,47	12,27	5,86
plastic coated paper	4,71	84,20	8,45	2,64
waxed milk carton	3,45	90,92	4,46	1,17
junk mail	4,56	73,32	9,03	13,09
Food/garden waste [% by weight]				
vegetable food waste	78,29	17,10	3,55	1,06
meat scraps	38,74	56,34	1,81	3,11
fried fats	0,00	97,64	2,36	0,00
lawn grass	75,24	18,64	4,50	1,62
leaves	9,97	66,92	19,29	3,82
green logs	50,00	42,25	7,25	0,50
evergreen shrubs	69,00	25,18	5,01	0,81
flowering plants	53,94	35,64	8,08	2,34
wood and bark	20,00	67,89	11,31	0,80
Household waste [% by weight]				
leather shoes	7,46	57,12	14,26	21,16
rubber	1,20	83,98	4,94	9,88
upholstery	6,90	75,96	14,52	2,62
polystyrene	0,20	98,67	0,68	0,45
PPVC	0,20	86,89	10,85	2,06
linoleum	2,10	64,50	6,60	26,80
rags	10,00	83,34	3,46	2,20
vacuum cleaner dirt	5,47	55,68	8,51	30,34

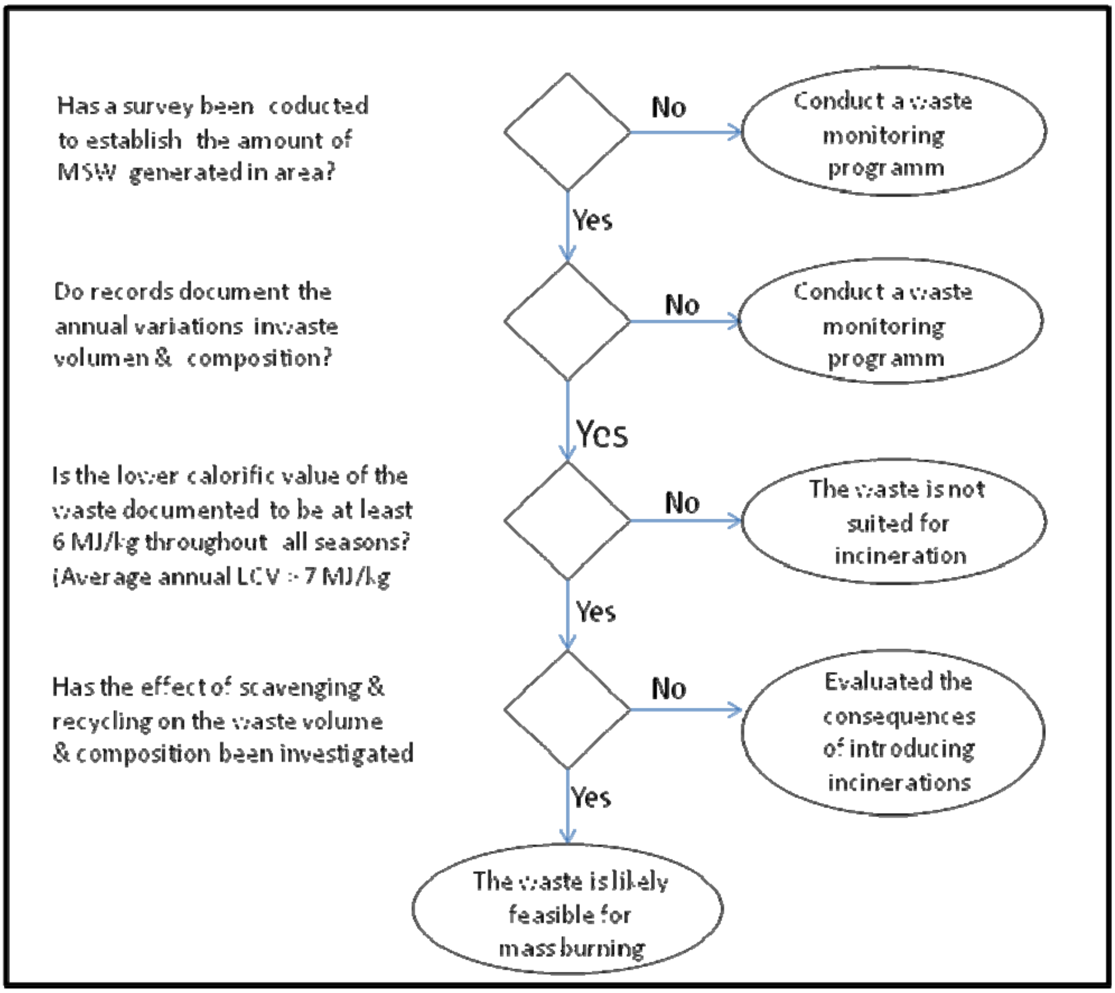
Source: Kaiser 1978

Table 6. Typical value for the ultimate analysis

Component of waste stream	C	H	O	N	S
Paper/paper products [% by weight]					
paper mixed	43,41	5,82	44,32	0,25	0,20
newsprint	49,14	6,10	44,03	0,05	0,16
corrugated boxes	43,73	5,70	44,93	0,09	0,21
plastic coated paper	45,30	6,17	45,50	0,18	0,08
waxed milk carton	59,18	9,25	30,13	0,12	0,10
junk mail	37,80	5,41	42,74	0,17	0,09
Food/garden waste [% by weight]					
vegetable food waste	49,06	6,62	37,55	1,68	0,20
meat scraps	59,59	9,47	24,65	1,02	0,19
fried fats	73,14	11,54	14,82	0,43	0,07
lawn grass	46,18	5,96	36,43	4,46	0,42
leaves	52,15	6,11	30,34	6,99	0,16
green logs	50,12	6,40	42,26	0,14	0,08
Evergreen shrubs	48,51	6,54	40,44	1,71	0,19
Flowering plants	46,65	6,61	40,18	1,21	0,26
Wood and bark	50,46	5,97	42,37	0,15	0,05
Household waste [% by weight]					
Leather shoe	42.01	5,32	22,83	5,98	1.00
Rubber	77.65	10,35	-	-	2.00
Upholstery	47.10	6,10	43,60	0,30	0,10
Polystyrene	87.10	8,45	3,96	0,21	0,02
PVC	45.14	5,61	1,56	0,08	0,14
Linoleum	48,06	5,34	18,70	0,10	0,40
Rags	55.00	6.60	31,20	4,12	0,13
Vacuum cleaner dirt	35.69	4,73	20,08	6,26	1,15

Source: Kaiser, 1978

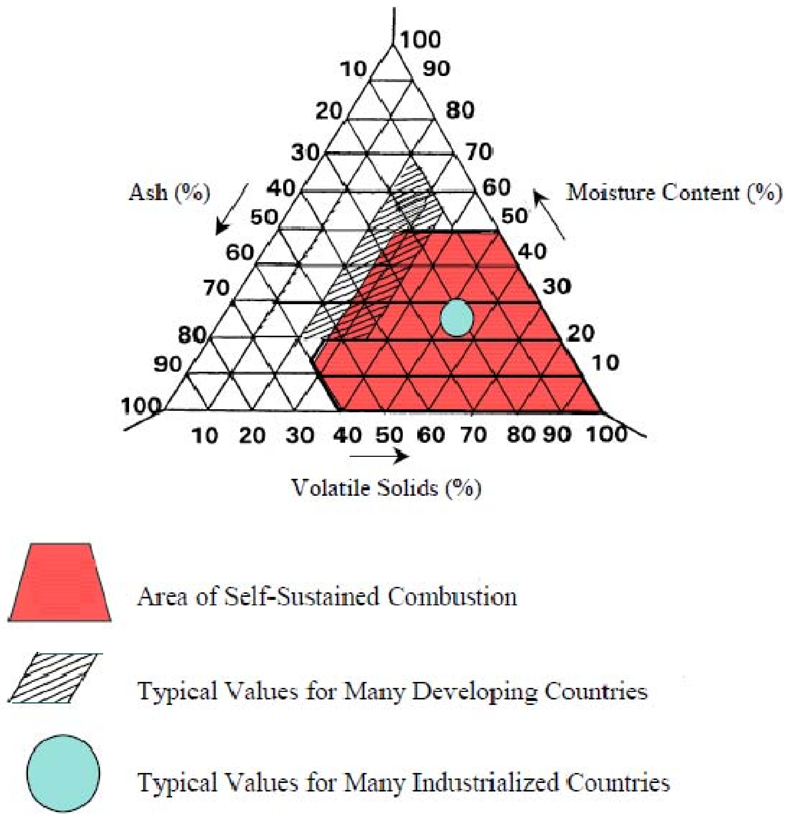
Combustion method for waste treatment such as incineration can be implemented along with other final waste treatment methods in order to reduce the waste disposed of in landfill. However, there are some considerations to determine whether incineration is feasible for final waste treatment or not. Rand et al. (2000) suggested a measure which is a flow chart to ascertain whether an incineration method is feasible or not based on technical requirements (Figure 3). The incinerator is appropriate to be implemented if the low heat value (LHV) of the waste for the combustion process is consistently more than 6 MJ/kg. Therefore, before deciding such combustion method, the calorific data on waste should be recorded continuously during the year to ensure the feasibility of input for the incineration plant. The minimum average annual calorific value should be 7 MJ/kg.



Source: Rand, et. al (2000)

Figure 3. Assesment Municipal Waste for Incinerator

Furthermore, waste composition should be also considered as it influences the waste calorific value (Buekens and Patrick, 1985; Hall and Knowles, 1985). Figure 4 describes the solid waste composition which is feasible for incineration. The moisture, volatile component, and ash in solid waste are the main factors affecting the waste calorific value. The high moisture content reduces the gross calorific value of the waste because the heat contained must first be supplied to remove moisture and can preclude the ignition. Volatile matter contains the combustible fraction of the waste beside other gases such as hydrogen, carbon monoxide, methane. Meanwhile, ash contains inert non-combusted material such as glass and metal. Incineration can be applied if the composition of municipal solid waste is inside the shaded area represents the typical composition of municipal solid waste which can sustain combustion without the requirement for auxiliary fuel. The shaded area covers the maximum acceptable moisture content and non-combusted material as well as the minimum allowable volatile matter. The modification of the content by treating the waste prior to the combustion can change the parameter values. For example, separating the glass and metal from the waste will increase the calorific value, while removing paper and plastic from waste can decrease the calorific value. Moreover, decreasing the organic content waste will reduce moisture content causing calorific value increase.



Source : UNEP (2005[a]); WB, (1999[a])

Figure 4. Feasibility of Incineration Method and Thermal Characteristic of MSW

3.5. Closing and upgrading the existing landfill

There are basically three methods in disposing municipal solid waste, namely open dumping, controlled landfill and sanitary landfill. Open dumping is not appropriate method because it can pollute the surroundings and involves activities of littering, illegal dumping and disposing in non-approved sites (Wastesolutions, 2004). Since the site is illegal, usually it is not equipped with the standard procedures to hinder the detrimental environmental effects, such as bottom liner to protect the water table, control well to measure the possible leachate intrusion, soil covering to avoid GHG emission and odor nuisance. Moreover, there is no waste segregation to restrict the household hazardous waste (HHW), such as paint, pesticides and batteries (UNEP, 2005[b]). Open dumping causes adverse environmental effects. Therefore, the practice of waste disposal using this method should be eliminated. Implementation of controlled landfill and sanitary landfill can replace the open dump site. In controlled landfill, the basic requirements for adequate infrastructure and equipment are fulfilled since its operation is subject to a permit system and to technical control procedures in compliance with the national legislation force. This includes also specially engineered landfill (EEA, 2007). However, controlled landfill operation focus on operational and management aspect improvement rather than on facility or structural improvement which would requires substantial investment (UNEP, 2005[b]). Meanwhile, the safe landfill practices is implemented in sanitary landfill since it is an engineered method of disposing of solid waste on land in a manner that protects the environment by spreading the waste in thin layers, compacting it to the smallest practical volume and covering it with compacted soil by the end of each working day or at more frequent intervals if necessary (EEA, 2007). In contrast to open dump and controlled landfill, sanitary landfill are designed and planned thoroughly from site selection up to post closure management and it requires substantial investment (UNEP, 2005[b]).

There are two possibilities to shift from open dumping practices to other environmentally sound manner in disposing waste. The first is closing the open dump site and constructing the new disposal site for controlled landfill or sanitary landfill. The second is upgrading the open dump site to a controlled landfill. Upgrading the open dump site to a controlled landfill does not require a new site. The disposal site can be the previous open dump site. However, leveling and compacting of existing waste as well as construction of drainage canals or ditches are required. If the new site will be constructed, the open dump site has to be closed. Closing an open dump site necessitates final soil cover provision, vegetation layer, drainage control system, leachate and gas management systems, monitoring systems and site security. Moreover, the cost for constructing new controlled landfill will be essentially the same as the upgrading from open dump site, only the land acquisition cost has to be considered. Therefore, selecting the appropriate method should be adjusted to the local conditions such as available technology, human resources, and finance (UNEP, 2005[b]).

3.6. Emergy analysis for Environmental Assessment

Emergy analysis is one of some existing methods for environmental assessment based on energy and energy quality as the main driving forces supporting systems and ecosystems. The concept has been developed by late Odum, an American professor and ecologist who recognized the role of the environment played in the economy. He assumed that economic activities were formed not only by economic rules but also by ecosystem constraints. His concept was that energy offered a common ground for integrating economic and ecosystems sciences. Therefore, he was trying to find a common unit or formula which could cover different energy flows, provide a possibility for comparison of different resources, products or even money with each other and not only the well known ones like heat flow. Every product on earth is generated through a set of energy transformation steps which are ultimately controlled by three basic sources of energy, i.e. sunlight, geothermal or deep earth heat and tidal or gravitational forces. By using the emergy analysis, this set can be identified and the amount of energy from the basic sources can be determined.

Emergy analysis provides a measure of the past and present environmental support to a process, allowing exploring the interplay of natural ecosystem and human activities. The emergy analysis can answer the problem of how to solve and analyze environmental problems which have social, economic and ecological consequences. It is useful to integrate resource limitations, labor, energy and their contributions into the formulations of economics. It also characterizes all the products and services in equivalent of solar energy. It means, how much energy would be needed to perform a specific work if the only input were solar energy. Therefore, the different forms of energy, materials, human is converted into equivalents of only one form of available energy, the solar energy, expressed as solar equivalent Joule (seJ). It represents the energy which was used to make a present product or service and now that energy is embodied in it called emergy. Emergy is a rename for **embodied solar energy** and defined as the sum of all inputs of energy (exergy) directly or indirectly required by a process to make any products or services. (Odum, 1996; 1998; 2003). Unit emergy value (UEV) is a measure used in emergy analysis to compute the emergy required to generate one unit of output from a process. There are several types of UEV which are (Brown and Ulgiati, 2004[b]);

a. Transformity: the ratio of emergy required to make a product and energy of the product expressed in solar equivalent joules per joule of output flow (seJ/J). A transformity (τ) for a product is calculated by summing all of the emergy inflows to the process (Em) and dividing by the exergy or the available energy (B) of the product as shown in Equation 3

$$\tau = Em/B \quad (3)$$

Transformities are used to convert energies of different types to emergy of the same type. The values transformity depend on the path taken to reach the state. Basically, the scale of energy transformations increases downstream (Odum, 2003). This path dependence makes it more challenging to determine these variables, since their values may change with the efficiency of the transformation processes. The transformities of ecological products and services vary over a very narrow range since these processes have evolved to be very efficient. Odum has been calculated the transformities of ecological product. Meanwhile, the transformity of industrial products and services varies according to the selected raw materials, and the production efficiency (Bakshi, 2000).

b. Specific emergy: the emergy per unit mass of output, and usually expressed as solar emergy per gram (seJ/g). Material resources may best be evaluated with data on emergy per unit mass.
c. Emergy per unit money: the emergy supporting the generation of one unit of economic product (expressed as currency). Emergy per unit money is the ratio between the total emergy use of a state and its gross domestic product (GDP). It represents the emergy needed to generate one unit of economic product and measures the money that circulates in an economy as the result of the some process. Its unit is emJoule/$ and defined in Equation 4 (Odum, 1996). In Indonesia, the value of the emergy per unit money was provided by University of Florida using data base of year 2000 and amount to 2.06E+13 seJ/$ (Univ. Florida, 2000). Therefore, in this study, services is evaluated by multiplying dollars paid for service by 2.06E+13 seJ/$.

$$Em = F * (Em_{nation}/F_{nation}) \quad (4)$$

where:
Em : emergy
F : economic input
M_{nation} : nation's emergy
F_{nation} : nation's GDP

d. Emergy per unit labor: the amount of emergy supporting one unit of labor directly supplied to a process. The UEV is expressed as emergy per time (seJ/yr; seJ/hr) or emergy per money earned (seJ/$).

e. Empower: The emergy per unit of time and has the unit of seJ/s, seJ/year, etc.

The emergy indices can be used to evaluate the performance of the process. The emergy indices which are common to be analyzed are (Odum 1996; Odum 1998; Ulgiati, 1995; Ulgiati, 1998; Ulgiati, 2002, Brown, 1997; Brown 2003);

a. Environmental loading ratio (ELR)

   ELR represents the ratio of purchased (F) and non renewable emergy (N) to locally free environmental emergy (R). It is an indicator of the pressure of the activities on the local ecosystem.

b. Emergy yield ratio (EYR)

   EYR is the ratio of emergy recovery (ER) to emergy investment (EI). It reflects the capability of the activities to exploit the local resources and the net benefit to the economy.

c. Emergy sustainable ratio (ESI)

   ESI is the ratio of the EYR to the environment. It is indicates whether the process provides a sustainable contribution to the user with a low environmental pressure. It measures the emergy yield per unit environmental load.

d. Net Emergy

   Net emergy is the difference between the emergy recovery and emergy investment. It indicates the net benefit of the activities.

Basically, there are five steps in emergy analysis which are described briefly in this study. A complete description of the emergy analysis methodology may be reviewed in publications by Odum (1996, 1998).

1. Data and information acquisition and collection. List of input and raw data related to subject.
2. Data categorization. Categorization is used to make analysis easier and to avoid double counting. The input data can be categorized into three main resources, namely renewable resources, non renewable resources and inputs from economy. Renewable and non renewable resources is provided by environment, free or purchased. Meanwhile, the last input is provided by the market and related to the fluxes that are accounted by the economy.
3. Process description and emergy system diagram determination. Firstly, the boundary of the investigated system is identified. Secondly, the diagram of emergy system including economic and natural resources are drawn. Emergy system diagram contains

a set of symbols for the visual modeling of environmental systems and describing the emergy flows into and out from as well as inside the boundary of the system (Odum, 1996). It helps to understand the way how the problem is surrounded, and how the main mechanism looks, in general. Figure 5 and Figure 6 shows the basic common symbols used in most systems modeling and the emergy system diagram in general respectively. More of the Odum symbols can be found in Odum's publication.

4. Transformity value determination. Some references provide the typical transformity value for resources. The transformity value can be also calculated based on the local conditions by dividing the total solar emergy inputs with the energy of the yield or mass output
5. Making of emergy table which contains of items, raw data (input/output pathways) or available energy, unit, transformity, solar emergy and emergy per unit money as described in Table 7.

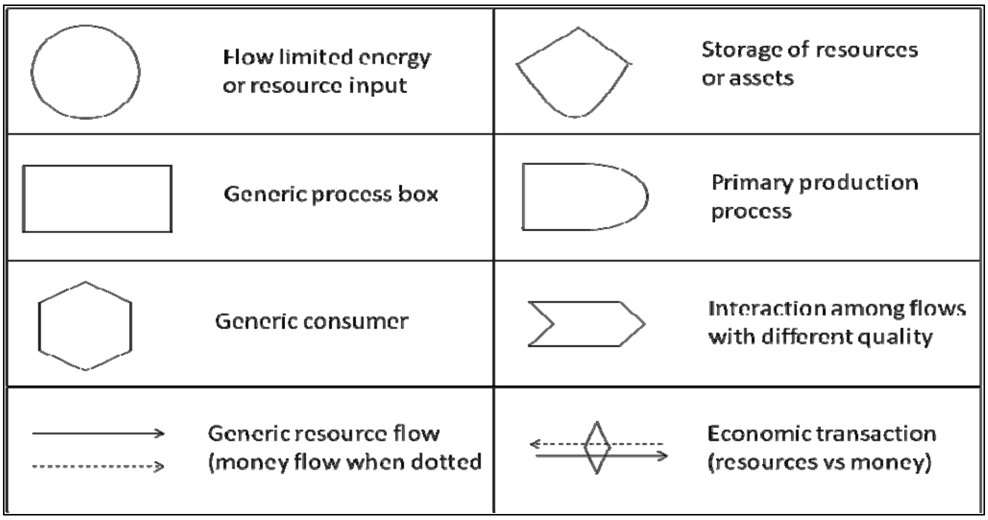
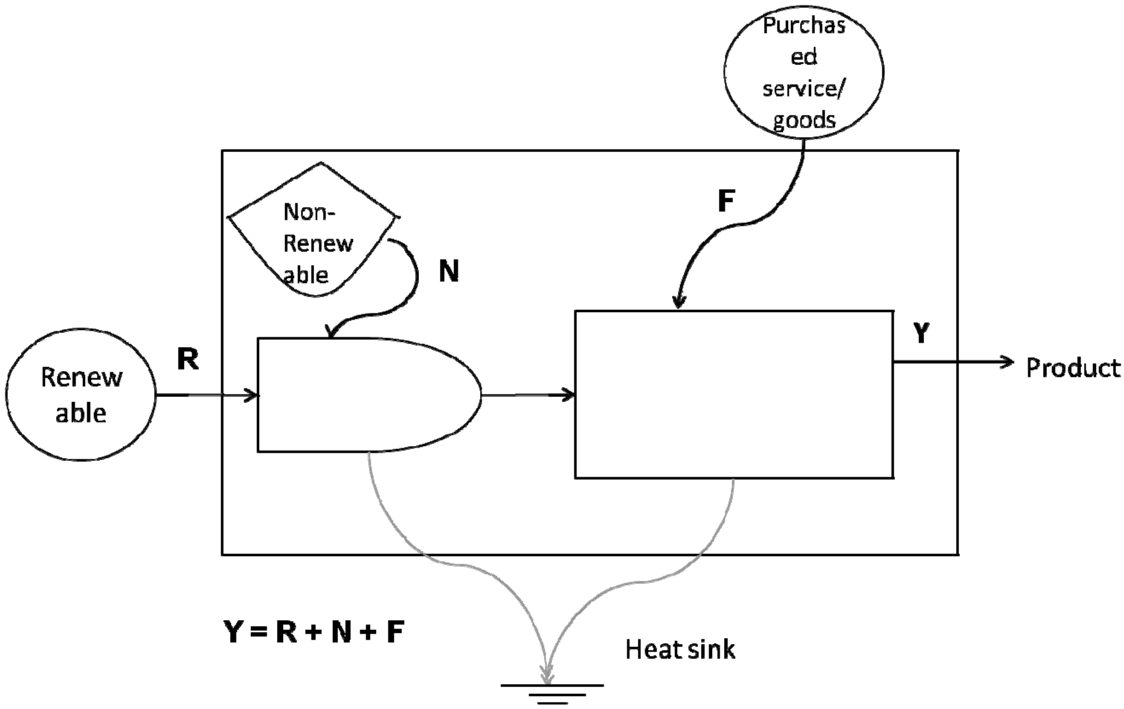


Figure 5. Basic common symbols used in emergy anaylsis (Ulgiati, 2007**)**



Source: Odum, 1996

Figure 6. General emergy system diagram

Table 7. Construction of Emergy Table

1	2	3	4	5	6	7
Note	Item	Raw data	Unit	Transformity	Solar emergy	Emdollars
Row 1						
Row 2						
Row 3						
Row 4						
Row 5						

Source: Odum (1996)

The row describes an inflow or outflow pathway. Pathways are evaluated as fluxes in units per year.

Column 1 : The number of the item evaluated and corresponds also to a footnote where raw data sources are cited and calculations shown

Column 2 : The name of the item/flow

Column 3 : The actual units of the input/output pathways usually evaluated as flux per year. Source, derivation and characteristics of these data can be put in the footnotes or appendices

Column 4 : The unit used in the analysis. It could be Joule, gram or currency ($, €, etc).

Column 5 : The value of transformities and specific emergies, usually derived from previous studies.

Column 6 : Solar emergy is the product of the raw units in column 3 and the transformity/specific emergy in column 5.

Column 7 : EmDollars are obtained by dividing the emergy in column 6 with the emergy-to- money ratio (calculated independently) for the economy of the nation in the selected year. The emergy investment can be also put in this column if it is more necessary to consider the emergy investment than the EmDollar

4. Municipal Solid Waste Management

4.1. Waste management policies and measures in EU and ASEAN

The discussion in this chapter aims to describe the role of policies in regional/national level in municipal solid waste management (MSWM) between two different background situations and to learn the lesson for the improvement of MSWM and especially landfill practices in Indonesia.

The existence of legal framework in regional level (EU) has pushed the EU- countries to manage waste sector in proper way regarding GHG emission reduction EU-15's target, 8% reduction by 2012 compared to 1990 (EC, 2010). Before mid 1970's, there was no legislation in waste disposal in EU (Crawford and Smith, 1985). It began in 1970's when waste policies have been considered both in the EU and in individual EU member states. Council Directive 75/442/EEC was the mile stone as it was a waste framework directive enacted in 1975. Council Directive 75/439/EEC on the disposal of waste oils was enacted on 16 June 10975 afterwards and followed by Council Directive 78/176/EEC of 20 February 1978 on waste from the titanium dioxide industry. Along with the EU policy development, there are revisions and replacements of the existing policies. Monkhouse (2003) had summarized the development of EU policies in waste management by dividing them into three periods 1975-85; 1986-96 and 1997-2003. Based on the actual situation, the author modified and divided it into four periods. Table 8 illustrates the EU policies development in four periods.

Table 8. Development of waste policy in the European Union.

Policy	Phase I (1975-1985)	Phase II (1986-1996)	Phase III (1997-2007)	Phase IV (2007-now)
Waste Management	Directive 75/442	Directive 91/156	Directive 2006/12	Directive 2008/98
Waste Oils	Directive 75/439	Directive 87/101	Directive 2000/76	
PCBs & PCTs	Directive 76/403	Directive 96/59		
Hazardous Waste	Directive 78/319	Directive 91/689		
Packaging	Directive 85/339	Directive 94/62	Under revision (COM (2001) 729	
Batteries & Accumulators		Directive 91/157	Directive 2006/66	Directive 2008/12 Directive 2008/103
Incinerators		Directive 89/369 Directive 89/429 Directive 94/67	Directive 2000/76	Directive 2008/1
Landfill			Directive 1999/31	
Waste Electrical & Electrical Equipment (WEEE) & The Restriction of Hazardous Substances (ROHs)			Directive 2003/96 Directive 2003/95	

Basically, the EU's current waste policy is based on the waste hierarchy which is the first aim is waste prevention, then reducing waste disposal through re-use, recycling and other waste recovery operations. In the future, the modern waste management in EU member states will be addressed to avoidance, recycling and treatment. Some regulations have been set up to strengthen the EU waste policies. For example, the EU sustainable development strategy (SDS) and the sixth environment action program (6EAP) which purposes to emphasize the use of resource and waste to protect the environment (EC, 2010).

There are various regulations and standards for waste management introduced in ASEAN countries. The standards and laws of each country describing the government's priority in managing waste according to local conditions. Many laws are actually environment-related laws which cover waste treatment in municipal waste management and only few are addressed to municipal solid waste management. Table 9 shows the waste management policies in ASEAN countries.

Table 9. Existence of Waste Management Policies in ASEAN Countries

Country	Regulations/laws			
	Environmental Protection	Hazardous waste	Waste management	Solid waste management
Brunei Darussalam	A	NA	A	NA
Cambodia	A	A	A	A
Indonesia	A	A	A	NA
Lao PDR	A	NA	A	NA
Malaysia	A	A	A	A
Myanmar	A	NA	NA	NA
Philippines	A	A	A	A
Singapore	A	A	A	A
Thailand	A	A	A	A
Vietnam	A	A	A	A
NA: Not Available A : Available				

Source: Abdullah, 1989: Bai, 2002; Manaf, et.al, 2009; Meidiana, 2010[b] UNEP, 2004; UNEP, 2010[b]; WB, 1999[c]

In regional level, the ASEAN (Association of South East Asian Nation) countries have many agreements about controlling the environmental degradation. Most of them are in form of development co-operations or declarations related to environmental issues. Since 1977, ASEAN has developed a series of ASEAN Sub-regional Environmental Programs (ASEP) called ASEP I (1978 - 1982), ASEP II (1988 - 1992) and ASEP III (1994 - 1998). These programs were continued by the strategic Plan of Action on the Environment 1999 - 2004. The current ASEAN environmental policy is Vientiane Action Plan (VAP) which came into force in 2004 and has ended in 2010. Along with these programs, several declarations and resolutions such as Manila Declaration on the ASEAN Environment (1981), Kota Kinabalu Resolution on the Environment (2000), and Joint Declaration on the Attainment of the Millennium Development Goals in ASEAN (2009) were enacted (ASEAN, 2011). Though available policies on the environment, there are no legal frameworks or policies on the waste issues used as a precedence in managing waste for the ASEAN countries. Harmonizing perception in waste problems among ASEAN countries by proposing general missions and visions in attaining better waste management is necessary for two reasons. First, since all of the ASEAN countries are belong to the Non-Annex I countries in Kyoto Protocol, they have the opportunities in proposing Clean Development Mechanism (CDM) Projects from waste sector. By having a general policy in waste management, the ASEAN countries can set targets and goals in reducing global green house gas emission and increase their regional capability in negotiating with Annex-I countries having interest in reducing their GHGs emission. Second, the ASEAN environmental policies can be used as tool to drive and to motivate the ASEAN countries to improve national waste sector management. It will be beneficial for the country itself and the ASEAN since adverse impacts of waste can across the geographical and administrative boundary, such as methane emission, marine litter, or upstream water pollution due to waste disposal into river. Compared to ASEAN, European Union (EU) has preceded in environmental issues

4.2. Waste Management Policies and Measures in Austria and Indonesia

Austria is a landlocked country with the total area of 84,000 km^2. Almost 62% of the area is mountains for its proximity to the Alps. Therefore, over half of the country is dominated by the Alps climate which is characterized by mountain climate with the average lowest temperature is -10˚C (in winter) and the average highest temperature is 39.7˚C (in summer). As a federal republic, Austria is divided into 9 states which are subdivided into districts comprising municipalities and statutory cities, cities with their own municipal laws. The population is estimated about 8.4 million inhabitants in 2011. The largest city is Vienna as the capital city with 1.7 millions population live in the city and 0.5 million live in the suburbs representing about a quarter of the country population. Other cities have fewer than 300,000 inhabitants. Austria belongs to the ten richest countries in the world with a GDP per capita US$ 39,711 (Rogers, 2011)

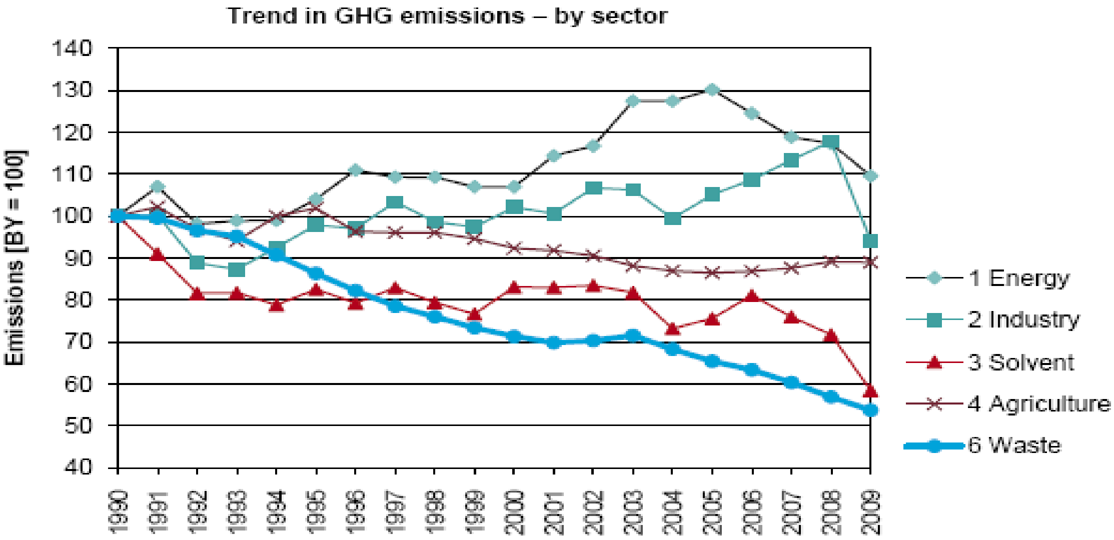
Historically, the initial development of national waste policies was started in 1977 when the Federal Ministry for Agriculture and Forestry issued the first technical guidelines on landfill requirements for waste disposal as response to the raising awareness of adverse impact caused by waste disposal leading to environmental degradation. Then, in 1983 the first Federal Act on Hazardous Waste Disposal was issued and the Environmental Protection Fund (*Umweltfonds)* was established in order to encourage necessary investments for waste treatment and new technologies in waste management. Since then, the government has been issuing waste legislations to meet the EU policy development and national waste sector dynamics. Table 10 shows the development of waste-related legislation in Austria.

Table 10. Development of waste-related legislation in Austria

Issue	Policy	Remarks
Environment	Federal Act 1984 Environmental Act 164/1998, Environmental Act 138/1999 Environmental Act 108/2001 Environmental Act 64/2002 Environmental Management Act 96/2001	
Hazardous waste (HW)	Environmental Protection Fund 1983 Waste management Act 1990 Austria Chemical Act 1996 Federal Law Gazette II 570/2003 Federal Law Gazette II 89/2005	The Act covers HW management
Waste management	Waste Management Act (WMA)1990 Waste Management Act (WMA) 2002 Federal Waste Management Plan	The later WMA is the reformulation of the previous WMA Implementation & achievement of WMA. SWM is included in WMA.
Recycling	Act 648/1996 Act 292/2001	
Landfill	Landfill Ban 1990/1992 Landfill Ordinance 1996 Landfill Ordinance 2006, 2008 Landfill Charge Act 1989	Landfill Ban for thermally, mechanico-biologically untreated waste came into force as 1st January 2004
Economic Instrument	Landfill Tax 1989 Packaging Collection System 1995 Deposit Refund Scheme 2004	
Packaging	Packaging Decree 1992 Packaging Target Decree 1992	

Source: **Eionet, 2006**

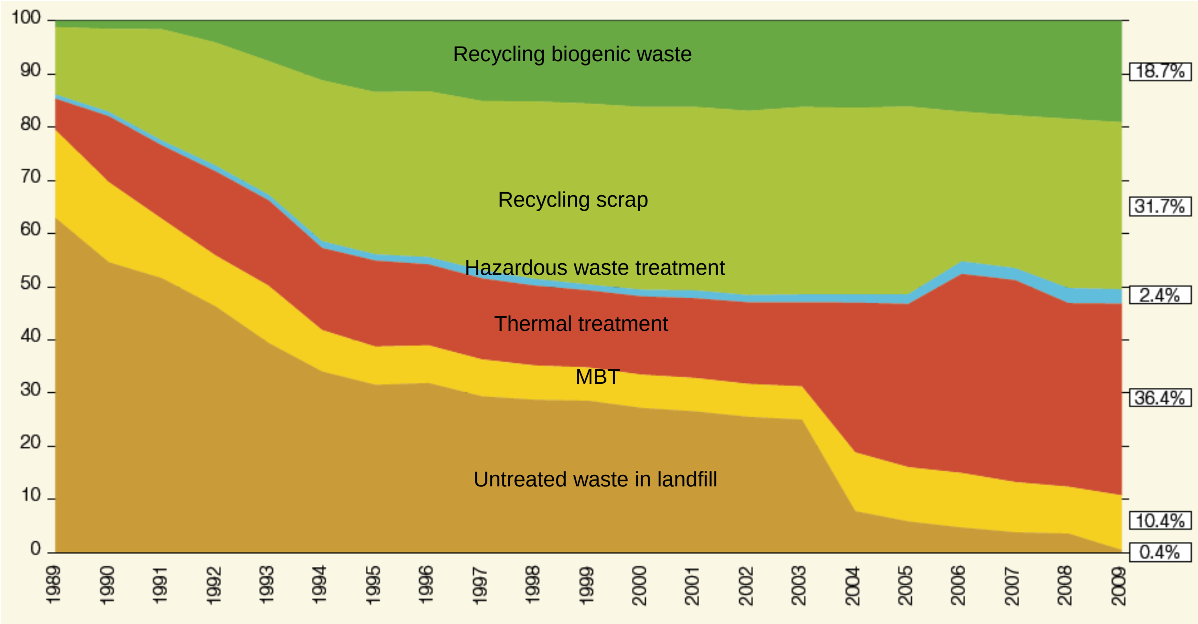
The implementation of waste policies in Austria has influenced the waste management development. In 1990, Green house gas (CO_2, CH_4, N_2O) emission from waste sector in Austria reached to the highest level ever measured from the sector, 3.6 million tons CO_2e. In 2005, GHG emission amounted to 2.3 million ton CO_2e and in 2010 amounted to 1.8 million ton CO_2e which indicates significant decrease (minus 49.8%) within 20 years. Waste separation, reuse and recycling activities have increased from 1990 as implication of some waste policies implementation. The amount of deposited waste has decreased especially since 2004 when pre-treatment of waste became obligatory. From 2009 until 2010, GHG emission decreased by 5.9% as result of the implementation of Landfill Ordinance (FEA, 2012). Figure 1 illustrates the declining trend in GHG emission from waste sector.



Source: FEA, 2012

Figure 7. Austria GHG emission from Waste Sector 1990 – 2009

The share of GHG emission for waste sector has decreased from 4.6% in 1990 to 2.1% in 2010. This achievement is a sign of effective waste law implementation in Austria, especially since the Waste Management Act came into force in 1990. The implementation of collection separation of biodegradable waste law (Act II 1992/68) and Packaging Ordinance in 1992 have contributed also to the achievement of the targets. In particular, municipal waste composted in Austria far exceeds composting levels of other countries. The regulation that bans the disposal of untreated BMW on landfill sites on 1st January 2004 strongly encourages this. The decrease amount of the waste disposed in landfill sited lead to increasing amount of waste incinerated. The ban on the landfilling of waste with total organic carbon (TOC) more than 5% has been an effective measure in reducing the amount of municipal waste going to landfill in Austria so that at the first year after the ban put into practice, there is a significant decrease of landfilled waste as described in Figure 8 (FEA, 2012). Thanks to these laws, Austria is the country with the highest material recovery rates in EU, nowadays. The use of economic instrument, such as landfill tax and deposit refund system has influenced also the reduction of waste disposed in landfill leading to GHG emission decrease from waste sector in Austria (EC, 2010).



Source: FEA, 2012

Figure 8. Development of Waste Treatment in Austria between 1990 and 2009

Indonesia is the world's largest archipelagic state having 234 million population inhabiting about 6000 of total 17,504 islands. The total area of Indonesia is 1,904,569 km² and about 60% of total population is living in Java Island which only occupies the area of 13,217 km² or 7% of the total area (Statistics Indonesia, 2011). The decentralization system has been applied since 1999 and province is the highest tier of local government led by a governor. There are currently 33 provinces in Indonesia and seven of which have been created since 2000. These provinces consist of regencies and cities. The decentralization system gives the regional government in province and local government in regencies and cities the authorities in determining their own policies and managing the local resources for development including the waste management policy.

Indonesia belong to the ten largest emitter in the world which accounts for approximately 5% of the world's emission (2,042 Mt CO_2e) and 9.3 tons of CO_2e per capita emission (56th highest in the world) in 2009. Actually, Indonesia has no obligation to reduce the national total emission to contribute global emission reduction since it belongs to country in non-Annex 1 in Kyoto Protocol. However, in Copenhagen Summit 2009, Indonesia announced a target of 26% emission reduction from 2009 level by 2020. Previously, Indonesia has ratified some international waste legal frameworks such as Basel Convention in 1993 and Kyoto Protocol in June 2004. The participation of Indonesia in some international agreements related to environment implies that the government's concerns about actual environmental problems including the potentially adverse waste effect on environment is arising (IPCC, 2006; MoE, 2005). Nevertheless, more actual efforts are needed because there is shortage of waste regulations in national and local level. There was no waste national policy until 2008 describing the concepts, aims and measures in national waste management. The existing related waste laws do not control solid waste management specifically. Generally, the existing laws cover the environment management, the hazardous waste management, waste recycling, pollution control, health and sanitation and the imported waste (UN, 2004). Furthermore, only few numbers of local governments which have policies related to waste before May 2008 when the new national waste law no. 18/2008 was enacted (Susmono, 2009[a]). Table 11 shows the existing law/policy/regulation related to the waste management in Indonesia (Meidiana, 2010[a]).

The new national regulation for waste management, Waste Law No. 18/ 2008 has been recently issued by the Government of Indonesian in May 2008 and become a legal tool in forcing all related parties to support the national waste management policies. The Waste Law 18/2008 covers issues related to public service principles, waste management, incentives and disincentives mechanism, funding scheme, shared responsibilities among waste authorities, private sectors participation, community based waste management and penalties for disobey. The share of responsibility among different levels of government focuses on increasing the role and responsibility of local government in waste management. The central government establishes the national waste policy and strategy, accommodates and develops the waste management cooperation between local governments, partnerships and networks, while the regional government determines the waste policy in lower level based on national waste policy. The local government has responsibilities to run waste management within the boundary based on the national and the regional waste law, to foster and to manage the local waste management implementation, as well as to control and to evaluate it. The local government has also authority in deciding the final waste treatment method. These responsibilities give the local government not only an opportunity, but also a challenge to improve the waste management since the Waste Law No. 18/2008 addresses to environmentally sound waste management practices. Article 22 defines this clearly by intending the implementation of environmentally friendly technology for final waste treatment while Article 44 intends the requirement of safe landfill practices. It obliges the local governments to have a planning of closing the old open dump site not later than one year after The Waste Law enactment and to close the final disposal site with open dumping method not later than five years after The Waste Law enactment. The Waste Law disobey can cause legal sanction and fines. Furthermore, the article 20 intends the possibilities to treat the waste before it is delivered to the landfill site (MoE, 2008[b]).

Table 11. Environment- and Waste-related Policies in Indonesia

Issue	Law/Regulation/Policy			Remarks
	Before decen-tralization in 1999	1999 – 2004	2005-now	
Environment	Regulation 24/1992 Act 23/1997	Regulation 27/1999 Ministerial Decree 86/2002	- Ministerial Decree 45/2005	Guidelines of env. management plan and env. monitoring plan
Hazardous waste	Ministerial Decree 42/MENLH/11/1994 Reg. 68/BAPEDAL/05/1994 Reg. 1 – 5/BAPEDAL/09/1995	Regulation 18/1999 Regulation 85/1999 Regulation 74/2001	Ministerial Decree 18/2009 - - -	
Waste management		-	Waste Law 18/2008	
Recycling		-	Ministerial Decree 2/2008	
Air and Water Pollution		Regulation 41/1999 Regulation 82/2001	- -	
Health & Sanitation		Law 7/2004 Ministerial Decree 288/2003 Law No 32/2004	Ministerial Decree 852/2008 Gov. Regulation 16/2005	Latest act regarding to Community based sanitation which refers to the previous one
Imported Waste	Ministerial Decree 230/1997 Regulation 18/1999		Ministerial Decree 41/2008 -	Ministry of Trade & Industry Regulation on non-HW import. Revision of previous Act.
Economic Instrument	Regulation 18/1997			

Source: **Meidiana, 2010[a]**

Environmental issues and hazardous waste is the main concern of the government so that the related policies/laws/regulations have been issued continuously before and after decentralization periods. Other policies such as imported waste and economic instrument for environmental issues were enacted before decentralization periods and have not been renewed until the second period. Meanwhile, regulations in air and water pollution were enacted in the second period. The policies in waste management and recycling have been issued as recently as in the third period. Though covering issues waste management more detailed compared to the previous environmental related policies, the new Waste Law does not include issue of integrated waste management. Program of 3R (Reduce, Reuse, Recycling) has been being promoted since 2007 as a proceeding of National Target regarding 3R in MSWM 2005-2009. The policies and strategic plans on MSWM such as MoE's Regulation No. 02/2008 Utilization of Hazardous Waste, MoPW Regulation No. 21/2006 on National MSW's Policy & Strategy, National 3R Strategy have been issued to achieve the targets. The targets for 3R in 2014 and 2019 includes reduction of disposal, composting of organic waste, and recycling of plastic, metal, glass and paper. Pilot projects initiated in 33 provinces were implementation of the program (Susmono, 2009[b]). In local level, all provinces and cities in Indonesia have the regulation related to cleaning management, institutional framework for waste management and waste management payment, but only some of them have the regulation on waste management even on solid waste management (Susmono, 2009[a]).

There is obviously different situation of the waste management in Austria as a developed country and Indonesia as a developing country. Austria has been practicing waste management since 1980s by implementing policies and measures related to waste management. As one of industrialized country ratifying the Kyoto Protocol, Austria is committed to reduce its GHG emission up to 13% from 2008 until 2012 below 1990 level (FEA, 2011). The implementation of current solid waste management is a way to achieve the targets. Meanwhile, Indonesia, though the available environment-related laws, has recently implemented the waste management by means of enactment of new Waste Law 18/2008. Thus, there is no waste policy in regional level (ASEAN) indicating that the waste sector has not been considered by the ASEAN. Consequently, it is optional for the individual ASEAN member states in enforcing the waste law in their own territory causing the lack of priority in national waste management. Indonesia experiencing the population increase is facing the waste problem since the waste generation growth is proportional to the population growth. Contrary to Austria, the GHG emission from waste sector in Indonesia is increasing. It is predicted that the amount will increase 3 times between 1995 and 2025 (Bengtsson, 2008).

Generally, the waste legal framework in regional and national level for both cases, Austria (EU) and Indonesia (ASEAN) is described in Table 12 (Meidiana, 2010[b]). Taking a lesson from the Austrian experience, it is noticeable that the waste management improvement can be initiated from the legal framework improvement.

Table 12. Comparison of current situation

Level		Regulation/law/policy							
		EP	HW	WM	3R	SW	EI	Pack.	LF
Regional	EU	A	A	A	A	A	A	A	A
	ASEAN	NA	NA	NA	NA	NA	NA	NA	NA
National	Austria	A	A	A	A	A	A	A	A
	Indonesia	A	A	A	A	NA	A	NA	NA

NA : Not available
A : Available
EP : Environmental Protection
SW : Solid Waste
Pack : Packaging
WM : Waste management
3R : Reduce, reuse, recycling
HW : Hazardous waste
EI : Economic Instrument
LF : Landfill

4.3. Waste generation and treatment

The increasing number of waste generation becomes a problem faced by national and local government. The total amount of waste generation in Indonesia was approximately 38.5 million tons in 2006 or about 100.000 ton/day (Susmono, 2009[b]). The amount is increasing along with the increasing population with the average growth rate of 1.52% per year from 2000 until 2010. The average waste generation in urban areas is higher than national average value because of 3.6% annual urban population growth rate (Statistics Indonesia, 2011). In urban areas, the total amount of waste generated can not be collected because of the limited level of service (LoS) as a common condition of the current situation of waste management in Indonesia. Besides, limited budget on investment and operation/maintenance (O&M) as well as lack of human resources is another predominant factors (Susmono, 2009[b]; Meidiana, 2011). In 2005, LoS of waste collection in Indonesia was approximately 41.28%. The percentage increased to 54% in 2006 and 56.4% in 2008 (MoE, 2008[a]). The GoI has to work seriously if they want to achieve the Millennium Development Goals (MDGs) target of 70% LoS in 2015 for urban waste service (Susmono, 2009[a]).

Household is the major source of solid waste and market is the second main waste source. As waste from these sources is characterized by high organic content, waste in Indonesia has a high organic content (Table 13, Table 14). Other sources of waste are street sweeping, public facility, commercial and industrial facility which generates waste with less organic content (MoE, 2008[a]).

The average solid waste generation in Indonesia was predicted 0.4 kg/cap/day in 1989 based on the country paper in 1987 (Lee and Troxler, 1991). Meanwhile, it is estimated that solid waste generation in major cities in Indonesia ranged between 0.66 to 0.90 kg/capita/day in 1998 (WB, 2004). In 2006, the amount increased approximately at 1.12 kg/capita/day indicating that there was a waste generation increase per capita (MoE, 2008[a]).

Table 13. Waste generation by Source in 2006

Source	Amount (million ton/year)	Percentage (%)
Household	16.7	43.4
Market	7.7	20.0
Street	3.5	9.0
Public facility	3.4	9.0
Office	3.1	8.0
Industry	1.3	6.0
Other	1.8	4.6
Total	**38.50**	**100.0**

Source: MoE, 2008[a]

The collected household waste will be treated through waste degradation in SWDS and composting centre, or waste processing through recycling. The uncollected household waste will be buried, disposed, open burnt done by community as described in Table 15. Unfortunately, many SWDSs are not well managed and operated as an open dump site causing environmental pollution through CH_4 emission and leachete intrusion into ground and surface water. (MoE, 2008[a]).

Table 14 Waste composition in 1989 and 2006

Year	Waste generation (kg/cap/day)	Composition (% wet weight basis)						
		Organics	Paper	Plastic	Glass	Metal	Textile/ leather	Inert/ Other
1989	0.40	87	2	3	1	4	NA	3
2006	1.12	62	9	14	2	2	4	7

Source: (MoE, 2008[a]), (Lee and Troxler, 1991).

Table 15 Household waste treatment in 2006

Method	Amount (Mio ton/yr)	Percentage (%)
Transported to landfill	11.60	69.00
Buried	1.60	9.60
Composted	1.20	7.15
Burnt	0.80	4.80
Disposed in river	0.50	2.90
Others	1.10	6.55
Total	**16.8**	**100.00**

Source: MoE (2008[a]).

Landfill is widely used as final waste treatment in the cities throughout Indonesia. Initially, the landfill was planned to be a sanitary landfill but then it is run as an open dump site. Composting, burying or open burning is a common method aside from landfill. In 2001, the municipal waste was treated through final disposal/landfill/open dumping (40.09%), open burning (35.49%), recycling (1.61%), buried (7.54%), disposed on street/in river/in park (15.27%) while in 2006 the amount of waste disposed to the landfill increased by 29%. The waste treatments done by the community exists in most Indonesian cities since the average LoS is still below 100%.

It is estimated that the emission from waste sector is approximately 8% of the total national GHG emission at national scale summed up to 166.8 Mt CO_2e out of 1,991 Mt CO_2e in 2005. The amount will increase as GHG emission is projected to reach 3,078 Mt CO_2e in 2025 along with the waste generation increase leading to waste disposal increase (MoE, 2010). The average growth of GHG emission from waste sector is approximately 1.2%. Methane is the major GHG emission from waste sector (95%) and it sources mainly from industrial waste water treatment and discharge (about 75%). Meanwhile, the open dump site contributes approximately 6% which is equal to 9.7 Mt CO_2e. Table 16 shows the increasing national GHG and methane emission from waste sector.

Table 16. GHG and Methane Emission from waste sector

	2000 [Mt CO_2e]	2001 [Mt CO_2e]	2002 [Mt CO_2e]	2003 [Mt CO_2e]	2004 [Mt CO_2e]	2005 [Mt CO_2e]	Growth [%]
GHG	157.3	160.8	162.8	164.1	165.8	166.8	1.2
CH_4	153.2	155.9	157.5	158.7	160.4	161.35	1.2

Source: (MoE, 2010).

The trend for GHG emission from waste sector shows that emission between 2000-2005 increases with the average growth 1.2% per year. The increasing trend in waste sector is mainly due to the increasing amount of waste delivered to the landfill.

4.3. Actors in waste management

Before the implementation of decentralization, MSWM is the responsibility of several departments and ministries such as The Ministry of Public Works, Ministry of Home Affair, Ministry of Health, Agency for Technology Assessment and Development, Board of Environmental Impact Management (BAPEDAL), and the Sub Directorate for Solid Waste Management. The involvement of many institutions in solid waste management led to overlapping responsibilities and weak implementation and enforcement of laws and regulations of solid waste management. The decentralization in 1999 had brought about the change in national and local waste institution in Indonesia. The central government plays role as a regulator and the local governments are the prominent players since then. The local government obtains more responsibilities in planning and implementing solid waste management in their locality. Moreover, there was change in national waste management structure in 2002, as the Presidential Decree No. 2/2002 was enacted. The Ministry of Environment took over the responsibility of BAPEDAL which was responsible for controlling environmental pollution impact. Since then, there are two institutions in national level responsible for municipal waste management, namely the Ministry of Environment and the Ministry of Settlement and Regional Infrastructure and three institutions at local level, namely BAPEDALDA or Local Board of Environmental Impact Management, BAPPEDA or Planning Agency, and Cleansing Department (Meidiana, 2010[a]). The Ministry of Environment is mainly responsible for policy developments, regulation formulations and coordination of efforts in control of pollution caused by waste. The Ministry of Settlement and Regional Infrastructure is mainly responsible for technical guidance provision, pilot projects promotion, and large-scale off-site sanitation systems supervision including waste management system supervision. Both of the ministries provide some sorts of training program for capacity building purposes. For example, Capacity Building in Urban Infrastructure Management (CBUIM) to increase the local government capability in providing urban services which was implemented between 1998 and 2003 by collaboration with some other donor countries. BAPEDALDA has the responsibility in controlling the environmental pollution impact, while Planning Agency (BAPPEDA) and Cleansing Department are responsible for the planning and implementation of solid waste management, such as transportation from the transfer points to the final disposal site. The municipality hires sometimes private companies to clean and to collect street waste in commercial areas. Some large commercial and industrial enterprises in big cities, like Jakarta, Bandung and Surabaya, have to landfill their own waste by either employing Cleansing Department and/or a private contractor (WB, 2004).

Basically, Private Sector Participation (PSP) in waste sector has been initiated since 1995 when the Indonesia's Program for Pollution Control, Evaluation, and Rating (PROPER) was initiated (Gozun, et. al., 2011; Roosita, 2004; WB, 1999[b]). However, the PSP mostly is not in form of direct involvement in municipal waste management system such as waste treatment or disposal but the participation of private sector (industries, factories) in such program pushing the industries to disclose their environmental performance to public and stakeholders. There is very little private sector participation in waste management, for example, Patriot Bangkit Bekasi Company which operates the Sanitary Landfill in Bekasi, West Java (Hilman, 2005). The industries participating in public disclosure system are encouraged to involve in implementation of pollution control regulations and to adopt practices contributing to "clean technology". They will be evaluated and rated by using a color coded rating, ranging from gold for excellent performance to black for poor performance. The implementation of PROPER 1995 influenced the industries' environmental performance. During the first pilot project period (June 1995 - March 1997) there were 187 industries involved and the percentage of the industries fulfilled the preferred parameter increased from 35% to 51%. In 1998, the number of industries in Sumatra, Java, and Kalimantan participating in the program expanded to 350 industries. In 2002, the Government through Ministry of Environment issued the renewed PROPER Program which included water, air and hazardous waste called PROPER 2002. The number of factories participating in the rate system during 2002 to 2004 decreased compared to 1998. There were 85 industries which were evaluated and the result showed the positive trend though the less number of involved factories. There was 81% decrease of factories with black category and 76% increase of factories with blue category (Roosita, 2004). Along with the PROPER-program, the government also has set a kind of partnership program in the hazardous waste management called KENDALI-Program by enacting of Regulation No. 03/1998. This program involved 141 industries which comply with Indonesian Regulation. 15% of these industries treat their own waste by the existing technology and 73% of industries send their wastes to the treatment facility.

There are various ways to involve the community in reducing and recycling the waste. The most easiest and common way is by charging them for waste retribution. Waste generator has to pay waste bill according to certain criteria such as house type, building function or electricity power (MoE, 2008[a]). The community initiative is still the best option for the local government because it can help the local government which can not provide good solid waste services for the community. There are a range of community initiatives, such as women-owned collection cooperatives, itinerant waste picker's improvement, and neighborhood-based youth groups for collection, contract to micro-enterprises, neighborhood composting or vermin-composting facilities, and collection of user charges from each household. For such services, the community has to pay small amount of addition cost for community savings used to pay operational activities for example; paying the salary of garbage collectors and street sweeper's, providing garbage bins and containers or purchasing of carts (UN, 2003; WB, 2004). In many Indonesian cities, all of the above practices are present with various modifications. The other ways to engage community in waste management are by implementing neighborhood waste treatment, introducing waste management in the schools, applying community based management and planning, and initiating waste separation closed to the source point. Communities provided with SWM service are obligatory to pay a collection fee since the collection of domestic waste is carried out by community neighborhood organization (RW's). The collection fee usually includes also other "community fees" such as security and environmental improvement contribution. Each household pays on monthly basis and the fee ranges from IDR 10,000 to IDR 30,000 (about US $ 1.1 – US $ 3.2). The amount of community fee charged depends on the living conditions of the residential area and is decided amongst community members. In addition to collection fees, there are also transportation and disposal costs of solid waste. The amounts charged for transportation and disposal costs depend on the dimensions (land area) of the residential plot. The payment for transportation and disposal can be done through water bill, electricity bill or direct payment. Households connected to the city water supply system pay their solid waste fees through their water supply bills. Thus the water supply bill includes the solid waste fee. The water supply company then delivers the payment to the account of the municipality on a monthly basis. Solid waste fees for transportation and disposal generally vary between IDR 6,000 - IDR 14,000 (US$ 0.55 – US$ 1.5). Direct payment is applied when the households are not connected to the water supply system (UN, 2003).

4.4. Financial Aspect on MSWM

One of the problems in waste management in Indonesia is financial shortage. Before the decentralization, the local government had received solid waste program financed by the centre government through national budget and by ADB (Asian Development Bank), IBRD (International Bank for Reconstruction and Development), JICA (Japan International Cooperation Agency) through loan. After the decentralization, solid waste program is mostly financed by local government which are from waste collection fee, waste retribution, and local governmental budget. However, the amount of the whole contribution is still low (about 2% of the total local budget) and can not fulfill the needed expenditure on waste management since the collection rate of the retribution amounted to only 40 - 50% of the revenue. Limited allocation for waste sector aspect leads to low level of service of municipal solid waste management. In 2001, only 34% of the population in Indonesia was provided by MSW service (WB, 2004). During 1990s, allocation for urban public infrastructure was approximately 0.4 percent of GDP which was about 8% of it (0.03% of GDP) spent on solid waste management. For example, in 1993, GoI allocated 0.34% of the GNP on municipal waste management. Compared to other ASEAN cities, this percentage was very low considering that Indonesia is the ASEAN country with the highest population. This allocation increased in the next decades but the percentage was still very low compared to the National Budget. Malaysia (Kuala Lumpur) and Vietnam (Hanoi) allocated about 0.38% and 0.80% of its GNP for municipal waste service in 1994 relatively. Meanwhile, Philippine (Manila) spent 0.37% of the GNP on solid waste management in 1995 (Farlane, 1998). Table 17 illustrates how much the municipalities in selected ASEAN countries expended their budget for urban waste management.

Table 17 Municipal Urban Waste Service Expenditure

City/country	Year	Expenditure on MWM (US$ per cap)	GNP per capita (US$)	GNP (%)
Kualalumpur/Malaysia	1994	15.25	4,000	0.38
Manila/Philippine	1995	4	1,070	0.37
Hanoi/Vietnam	1994	2	250	0.80
Jakarta/Indonesia	1993	1.77	740	0.34

Source: **Farlane (1998).**

In 2001 and 2002, waste sector belonged to environmental sector where the overall budget for environmental sector was only 1% of the National Budget (UNEP, 2004). Limited budget for waste management is the reason for some existing problems in landfill operation such as in adequate investment for sanitary facilities, low affordability in providing proper sanitary facilities for limited operational and maintenance cost, deprived quality and quantity in sanitary services. Consequently, the local governments can not operate the landfill which meets the requirements of the sanitary landfill (Hilman, 2005).

5. Research Methodology

5.1. Overview of the applied method

The area of study is Yogyakarta City as a representative of a big city which has a population about 460,000 inhabitants (MoPW, 1994). The municipality plans to close the old landfill (*Bendo landfill*) and will construct the new landfill not so far from the old landfill in 2012. Surveys for primary and secondary data have been carried out twice which includes the aspects related to the waste management in the city. The first survey was conducted in January until March 2010 and the second was in October 2010. Data on municipal solid waste were collected from waste authority in Yogyakarta to identify the general municipal solid waste management including the waste characteristic, the rate of waste generation, waste collection and waste transportation to the landfill. Data on waste were mainly sourced from statistics on waste management in 2004 - 2008, Regency/City Profile, Waste Status Report 2008 - 2009 and earlier studies about waste management in Yogyakarta . The stakeholders associated with solid waste management are the target for the survey. It comprises the local government, private sectors and the community including scavenger. Nevertheless, after the preliminary study, only two respondents were determined to be the main objects for the primary surveys, namely local government and scavengers. The private sector and the community is not the focus of the surveys since they are not much involved and the major concerns within the scope of study.

The surveys goals are the factors affecting the current conditions of waste management in Yogyakarta. Therefore, some aspects likely connected with the waste management, such as legal aspect, financial aspect, technology, natural features and social backgrounds were observed. The estimation of methane emission was also calculated as it was required to find out the methane generation potential from the typical waste in Yogyakarta. The result of the observation was used to determine the alternatives for the final waste treatment. The selection of the best alternatives was done with the use of IPCC Tier 2 method and emergy analysis. Figure 5 shows the analytical process for the scenario selection in determining the appropriate final waste treatment in Yogyakarta.

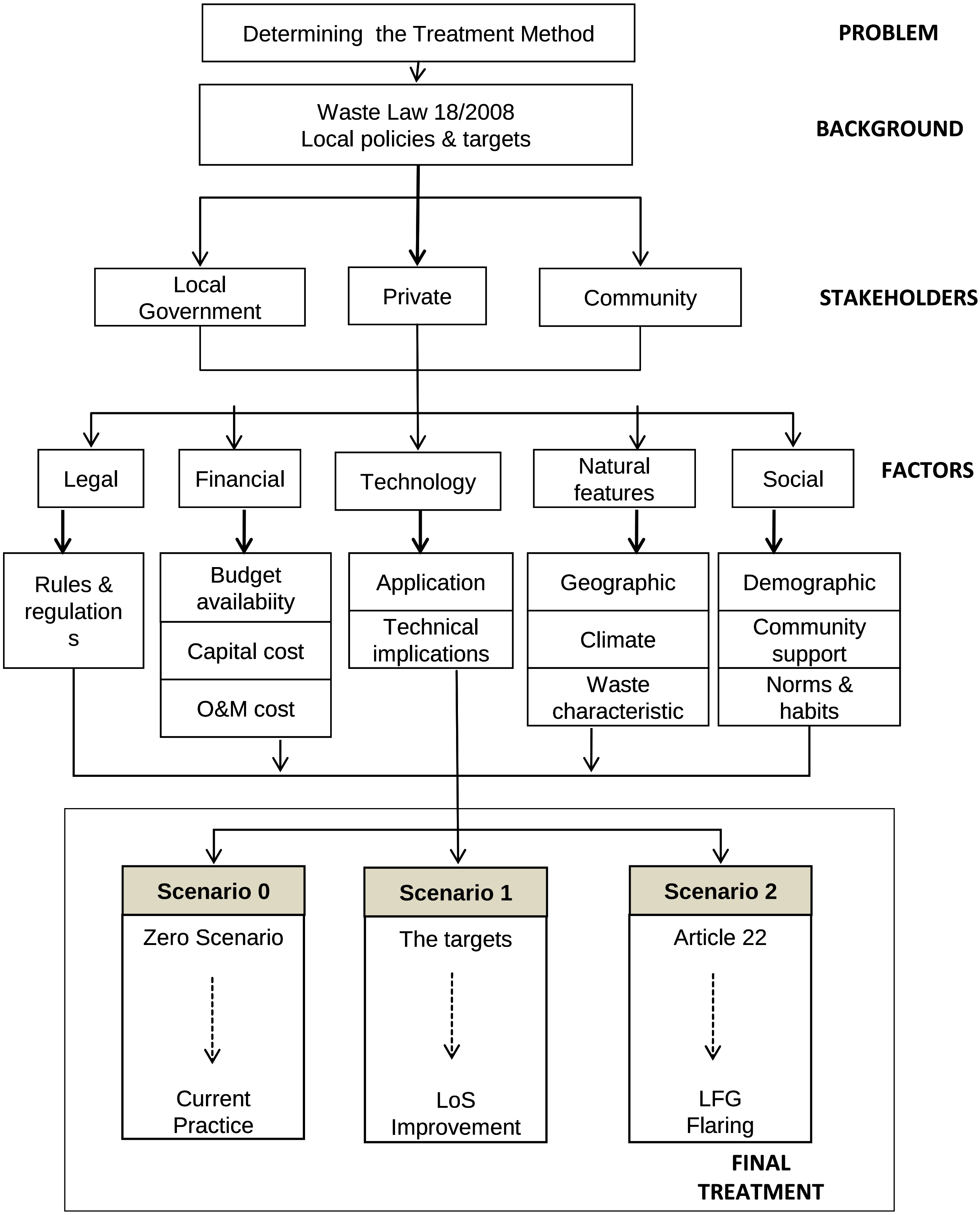


Figure 9. Analytical process for scenario selection

5.1.1. Sampling method

Survey for primary data was conducted by means of questionnaires to provide more recent data and through interview in order to follow-up the questionnaire answered by the respondents and to get in-depth information related to landfill operation. Questionnaires were distributed to two kinds of respondents. The first respondents were Municipality of Yogyakarta and Yogyakarta Environmental Board representing the stake holders involved in waste management. The second respondents were scavengers in landfill. Standard open ended interview was selected in which the respondents were asked with same open ended questions to get detailed information which is easy to be analyzed and compared. The questionnaire aimed to examine declared waste treatment in landfill, level of service (LoS) on waste collection, performance of existing landfill and to identify the issues that influence the LoS and landfill's performance.

The number of the scavenger respondent was determined using Slovin formula (Equation 5) proposed by Sevilla et. al., (1993).

$$n = \frac{N}{N.e^2 + 1} \tag{5}$$

Where:
n : number of required respondents
N : number of population
e : sample error

5.1.2. Methane generation calculation

The methane emission during the landfill time is estimated by means of time series data on waste disposal. However, the available time series data on waste disposal in Bendo landfill is only data from 2007 until 2010. Therefore, the time series data on waste disposal during landfill's lifetime was estimated using the available data on population 1993 – 2010 and waste generation 2004 – 2008. The average waste generation growth between 2004 and 2008 was used to complete the time series data. The waste generation per capita and the level of service (LoS) on collection was calculated using the time series data on population, waste disposal, and waste generation. Population from 2012 until 2028 is projected using Equation 6 (Shryock, 2004).

$$Pn = Po(1 + r)^n \tag{6}$$

Where:
Pn : Population in the projected period
Po : Population in starting year
r : The average annual population growth rate
n : The projection period (in years)

Methane emission from landfill is calculated through methane generation estimation using Equation 7 suggested by IPCC (2006).

$$CH_{4Emiss} = \left[\sum_x CH_{4generated_{x,T}} - R_T \right] * \left(1 - OX_T\right) \tag{7}$$

Where:
CH_{4Emiss} : CH_4 emitted in year T [ton/yr]
T : inventory year
R_T : recovered CH_4 in year T [ton]
OX_T : oxidation factor in year T (fraction)

Methane generation can be calculated if the mass of decomposable waste ($DDOC_m$), the mass of the accumulated decomposable waste ($DDOC_{ma}$), the mass of deposited decomposable waste ($DDOC_{md}$), and the fraction of methane in landfill gas (LFG) are known. Therefore, the procedures to calculate the methane emission have to be set off by calculating above variables using Equation 8 – 11.
The decomposable from waste disposal data can be calculated using Equation 8.

$$DDOC_m = W_T.DOC.DOC_f.MCF \tag{8}$$

Where :

$DDOC_m$: mass of decomposable DOC deposited [ton/year]
W_T : mass of waste disposed in year T [ton]
DOC : degradable organic carbon in the year of deposition, fraction [tonC/ton waste]
DOC_f : fraction of DOC that can decompose (fraction)
MCF : CH_4 correction factor for aerobic decomposition in the year of deposition fraction)

$DDOC_m$ accumulated in landfill at the end of year T is calculated using Equation 9

$$DDOC_{ma_T} = DDOC_{md_T} + \left(DDOC_{ma_{T-1}}.e^{-k}\right) \quad (9)$$

Where:

$DDOC_{maT}$	:	$DDOC_m$ accumulated in SWDS at the end of year T [ton]
$DDOC_{maT-1}$	:	DDOCm accumulated in SWDS at the end of year T-1 [ton]
$DDOC_{mdT}$	:	DDOCm deposited into SWDS in year T [ton]
k	:	decay rate [-]

Meanwhile, mass of decomposable DOC at the end of year T is calculated using Equation 10

$$DDOCm_{decomp_T} = DDOCma_{T-1}.\left(1 - e^{-k}\right) \quad (10)$$

T	:	inventory year
$DDOC_{maT-1}$	:	DDOCm accumulated in the SWDS at the end of year (T-1) [ton]
$DDOC_{mdecompT}$	:	DDOCm decomposed in the SWDS in year T [ton]
k	:	decay rate [-]

The annual methane generation can be calculated using Equation 11.

$$CH_{4generated_T} = DDOC_{decomp_T}.F.16/12 \quad (11)$$

Where:

$CH_{4generated}$	: CH_4 generation [ton]
$DDOC_{mT}$	: $DDOC_m$ decomposed in year T [ton]
F	: fraction of CH4 in generated landfill gas (fraction)
16/12	: molecular weight ratio CH_4/C (ratio)

The total methane generation is the sum of the annual methane generation. Due to the fact that there is no soil covering and LFG collection system in the old landfill, the terms of recovered methane and oxidation factor is negligible. As a result, the amount of methane emission equals to the amount of methane generation.

5.2. Assumptions and limitations

The study focuses on analyzing the alternatives for the final waste treatment. The scenarios were made considering the current situations and the Waste Law no. 18/2008 which requires safe final waste treatment method. The result of the study does not necessarily reflect the actual prediction of future situations because these can be affected by changes including in waste composition (which was kept constant in this study). There was no field measurement for the waste characteristic investigation. Therefore, some approaches such as the ultimate and the proximate analysis are applied to determine the waste characteristics. Some default values proposed by IPCC (2006) were used to calculate the LFG emission. Due to the lack of input data, the following major assumptions were made:

- Currency rate is Rp 9,500 for US$ 1 which is the average value of the predicted exchange rate of Rupiah from Central Bank ranging between Rp 9,000 - Rp 10,000 in 2010.
- Waste density is assumed 400 kg/m³ based on average domestic waste density in Indonesia proposed by Diaz et al. (1993). The assumption is made to convert some waste data which were in volume units to weight units.
- Waste generation rate per person is derived from the average amount of waste generation and number of population from 2004 - 2008.
- Waste percentages are kept consistent over the time period.
- Population growth is the average value over the period and kept consistent for the prediction.
- All material sorted by the scavengers in landfill will be transported for recycling, whereas the scavenging in community level is neglected because of unquantifiable data at present
- The emergy input from renewable and non-renewable resources per year are kept steady.

Some secondary data are required to be processed due to the following limitations:

- The waste tonnage disposed of in landfill in 2008 and 2009 was not complete. Therefore, the calculation is conducted using the percentage from data in 2010.
- The weigh bridge was failure between May and August 2008. The average waste percentage from nearest month is used to calculate the missing data.
- Different waste classification among the references necessitates modification of existing waste classification to make the physical, proximate and ultimate analysis possible.
- The percentage of metal and glass from typical waste composition in Yogyakarta was consequently used due to minimum data obtained from field survey.

5.3. Scenarios for future landfill operation in Yogyakarta

The results from the observation of the old landfill are also used as a reference in determining the alternatives. The scenarios include the calculation of environmental parameters (GWP and emergy value) from final waste treatment. The assumptions mentioned in the previous chapter are conditioned also to the scenarios. It is assumed that the waste collection is constant with the base year 2013 although the rate increases proportionally to the waste generation each year. The calculation in emergy analysis is based on yearly inputs and outputs. Consequently, the value from emergy analysis could be different if the growth rate of waste generation is considered. However, since the same assumptions are applied to all scenarios and the scenarios are compared using the same assumptions, it does not mean that the result of the comparison deviates.

The same procedures to calculate the emission from the old landfill is also applied in the new landfill. The prediction of waste generation is derived from the population projection. The result is used to calculate the waste which will be disposed of in the new landfill using the actual LoS. The assumptions for the parameters related to the waste management including the waste characteristic, waste percentage and waste composition are kept consistent. The physical and geographical properties of the site are assumed remain the same because of the proximity to the old landfill. Bendo landfill accepts the waste not only from Yogyakarta City, but also from other two counties (Bantul and Sleman). The percentage of the waste from these counties is kept consistent over the inventory years. The methane emission from the landfill is estimated using the IPCC Tier 2 method. The new controlled landfill will be constructed with following attributes:

- Landfill capacity is about 393 tons/day based on the average waste disposes of in Bendo landfill in 2010.
- The period time of landfill is 15 years, beginning from 2013 until 2028
- The new landfill will be operated as controlled landfill equipped by the following infrastructures and facilities:
  - Controlled access
  - Weigh bridge to measure waste receipts
  - Well maintained access roads
  - Compaction process in dumping areas provided by bulldozers
  - Frequent (once a month) soil covering of up to 20 centimeters (cm)
  - An adequate storm water run-off control system

    - Application of the lining system also has a high-density polyethylene (HDPE) geomembrane component to avoid leakage.
    - An internal leachate collection system
    - A leachate holding pond collect to treat the leachate from internal leachate collection system
- The landfill depth is minimum 5 meters and maximum 20 meters
- The equipment and the fleet used for waste treatment are kept constant though the increasing waste disposal

Entirely, there are three scenarios for the final waste treatment method in Yogyakarta presented in this study, i.e.;

1. **Scenario 0**: Zero scenario (Business as usual) is a base line scenario where the new landfill will be operated like the old landfill with the current average waste generation growth per year. Waste is delivered to the landfill without any further treatments and actual composting rate done by community is applied. There is no soil covering and LFG collection system. Furthermore, scavengers from the old landfill will be accommodated to sort the waste disposed of in the new landfill.
2. **Scenario 1**: Meet the target of improving the collection system. The Level of Service (LoS) of collection system will be increased according to the local government claim. The composting rate will be increased according to the local target and scavengers are allowed to work in the new landfill. There is soil covering but no LFG collection system.
3. **Scenario 2**: Meet the Waste Law 18/2008 policy Article 22 for environmentally friendly SWDS. The conditions related to LoS and composting rate in Scenario 1 are applied. Scavengers are allowed to work in the landfill. Soil covering is applied to the landfill and the collected LFG will be flared with the open flaring system. Scavenging is permitted in restricted landfill area, where LFG collection system is not constructed.

5.3.1. The Calculation of Global Warming Potential

The calculation of global warming potential from landfill is based on the calculation of the uncontrolled and controlled emission of the methane and carbon dioxide. The methane emission calculated using Equation 7 – Equation 11. Though the existence of the regular soil covering (once a month) in Scenario 1 and Scenario 2, the variable of oxidation factor is assumed to be zero as the default value from IPCC for the managed but not covered with aerated material. The condition of landfill with few frequency of soil covering is assumed to be the same as that of without soil covering. The uncontrolled CH_4 (U_{CH4}) and CO_2 (U_{CO2}) emission are emitted from the landfill where a collection/flaring system does not present. The uncontrolled methane emission is calculated using IPCC Tier 2 method. Controlled CH_4 (C_{CH4}) and CO_2 (C_{CO2}) emission in landfill are from collection and flaring system. The purpose of landfill gas flaring conditioned in Scenario 2 is to release the flammable constituents from the landfill safely and to control odor nuisance, health risks and adverse environmental impacts (EA, 2002). In this case, the gas flaring system is assumed to be open flares system. Open flare system is applied since it is quite appropriate for the local situation. It is inexpensive and relatively simple, which are very important factors when there are no emission standards. The controlled emissions of CO_2 (C_{CO2}) and CH_4 (C_{CH4}) are calculated using Equation 12 and Equation 13 respectively (Jaramillo and Matthews, 2005). The methane emission is then converted into emissions of CO_2 [CO_{2eq}].

$$C_{CH_4} = (1 - \eta_{col}) * U_{CH_4}) \tag{12}$$

$$C_{CO_2} = U_{CO_2} + (\eta_{col} * U_{CH_4}) \tag{13}$$

Where:

U_{CH4} : uncontrolled CH4 emission [ton]
U_{CO2} : uncontrolled CO2 emission [ton]
C_{CH4} : controlled CH4 emission [ton]
C_{CO2} : controlled CO2 emission [ton]
η_{col} : collection efficiency (fraction)

5.3.2. The Calculation of Emergy Values and Emergy Indices

In this study, the emergy of renewable resources, non-renewable resources, goods and services are calculated as the total amount of emergy flows required to treat the solid waste. The emergy flow of each input is then multiplied by suitable transformity to result in solar emergy.

The emergy analysis is applied to evaluate three different scenarios of final waste treatment, since there is a discussion among the decision maker about the appropriate final waste treatment method for Yogyakarta City. The evaluation includes how much investment is needed for each waste treatment method and how much usage is extracted from the methods. These are the emergy investment and emergy recovery. The emergy values are the emergy investment and the emergy recovery describes the emergy cost and emergy benefits from each scenario. The emergy investment is the measures of the solar emergy required for treating a unit (gram) of solid waste, while emergy recovery is the measure of solar emergy gained from the treatment of a unit (gram) of solid waste. Furthermore, some emergy indices are calculated. The emergy indices are the indicators for the performance of each scenario and Equation 14 – Equation 17 are used to calculate the emergy indices. The result of the calculation is evaluated based on the criteria of each index to judge the sustainability and efficiency of each scenario as described in Table 18.

$$EYR = \text{Emergy recovery}/\text{emergy investment} \tag{14}$$

$$\text{Net Emergy} = \text{Emergy recovery} - \text{Emergy investment} \tag{15}$$

$$ELR = NR+NP+RP/RR \tag{16}$$

$$ESI = EYR/ELR \tag{17}$$

Table 18 Emergy values and emergy indices analyzed in this study

Index	Abbreviation	Formula	Criteria
Renewable Resources (free)	RR		
Renewable Resources (purchased)	RP		
Non Renewable Resources (free)	NR		
Non Renewable Resources (purchased)	NP		.
Emergy investment	EI	Input emergy/unit MSW treated	The lower the value, the lower the cost.
Emergy Recovery	ER	Output emergy/unit MSW treated	The greater the value, the higher the benefit
Emergy Yield Ratio	EYR	EYR=ER/EI	The higher the value, the greater the return obtained per unit of emergy invested.
Net Emergy		Net Emergy = ER-EI	The higher the value, the greater benefit extracted
Environmental Loading Ratio	ELR	ELR=NR+NP+RP/RR	The lower the ratio, the lower the stress on the environment.
Emergy Sustainability Index	ESI	ESI=EYR/ELR	The higher the ratio, the more sustainable.

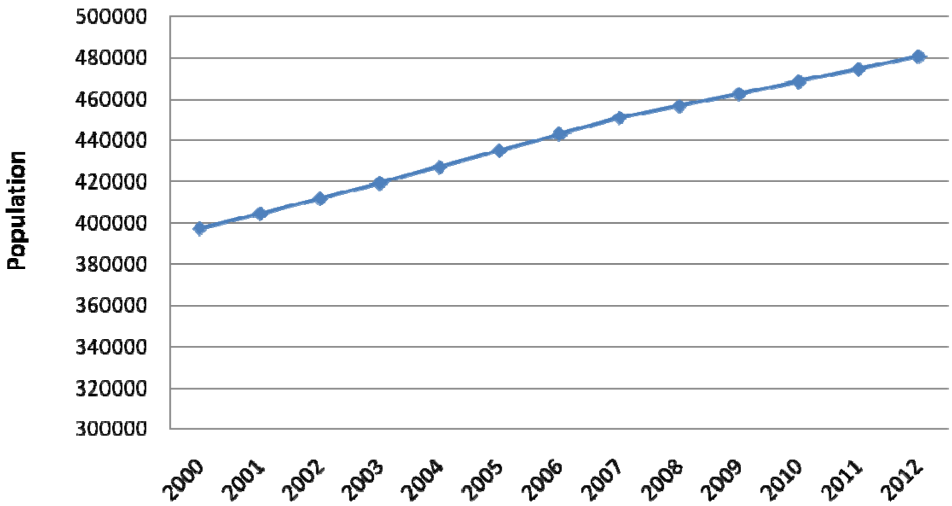
Emergy benefit can be calculated through emergy indices which are the ratio between output emergy and the emergy purchased from the market, including fuels, goods and services and/or the difference between them called environmental yield ratio (EYR) and net emergy respectively. They measure how much emergy has been saved by implementing the scenarios or particularly is a measure of the system's net contribution to the economy beyond its own operation (Odum, 1996). The EYR and Net emergy can be calculated by using Equation 14 and 15 respectively. The other emergy indices are environmental Loading Ratio (ELR) and Environmenta;l Sustainability Index (ESI) calculated using Equation 16 and 17. The calculation uses the recalculation values of the 1996 solar empower base (9.44E+24 seJ/yr). Therefore all unit emergy values calculated before 2000 is multiplied by 1.68 as the factor increase from 9.44E+24 seJ/yr to 15.83E+24 seJ/yr as the result of the increase in global emergy base (Odum, 2000; Brown 2004[a]).

6. Analysis and Findings

6.1. Municipal solid waste management (MSWM) in Yogyakarta

6.1.1. General Information

Yogyakarta City is situated on the Indonesian island of Java and has population of approximately 462,764 people in 2009 having grown from 397,398 people in 2000 (Figure 10). With the average population growth of 1.5%, it is predicted that in 2012 the population will be 480,763 people. Yogyakarta comprises 14 districts and 45 sub-districts covering a total area of 32.5 km² (Statistics Yogyakarta 2011). The city belongs to Daerah Istimewa Yogyakarta (DIY) Province together with 3 other counties namely KulonProgo, Sleman and Bantul. As the city situated on Merapi Mount’s Valley, it has an inclination between 0-2% and lies 114 meters above sea surface. Located in the tropical region, Yogyakarta has average rainfall of 1841 mm/year and the average rainy days per month are 6.92 days. The average humidity ranges between 66% and 85% and the mean temperature is 26.11°C (Table 19). The annual economic and the population growth rate in Yogyakarta city is approximately 4.3% and 1.5% respectively as presented in Table 20 and Table 21.



Source: Statistics Yogyakarta, 2011

Figure 10. Population growth in Yogykarta

Table 19. General Meteorological Data in Yogyakarta

Factor	Information
Temperature	An average temperature of 26,11C
Humidity	Humidity between 66% - 85%
Rainfall	Average rainfall 1841 mm/year
Topography	Inclination between 0 - 2%. Located (average) 114 meters asl. 3 rivers flow through the city

Table 20. Economic growth in Yogyakarta

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008
Economic Growth	3.6	3.07	3.86	4.76	5.05	4.87	3.97	4.46	5.12

Source : Statistics Yogyakarta, 2011

Table 21 Population growth in Yogyakarta

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Population Growth	1.80	1.79	1.79	1.79	1.87	1.81	1.8	1.28	1.28

Source : Statistics Yogyakarta, 2011

With the increasing population, it is projected that the waste generation will increase, too. The proper waste management is needed. Otherwise, the condition of waste management in Yogyakarta is getting worse.

6.1.2. Current conditions of MSWM in Yogyakarta

The national waste law, The Waste Law No. 18/2008 has been recently enacted in May 2008 but Yogyakarta have had regional related-waste law some years before 2008. It was The Law No. 22/2002 about community management in Yogyakarta which includes waste retribution and waste service. Beside the existing law, the municipality of Yogyakarta has some policies and targets on MSWM which is stated in City Ordinance No. 18/2002 (Zudianto, 2011).

The policies of Yogyakarta Municipality on MSWM are:

- to provide area for Sanitary Landfill
- to meet the requirement of adequate facilities and infrastructure for waste collection
- to improve community awareness in household waste management.
- to promote and disseminate 3R method
- to develop waste information system and data base
- to develop more effective cooperation mechanism with private sector

Meanwhile, the targets on MSWM are:

- to improve LoS of waste management .

- to implement sanitary landfill.
- to implement effective technology for waste treatment
- to improve private participation in municipal waste management

However, though the availability of waste policy in national and local level, the law enforcement in Yogyakarta City is still low causing the ineffectiveness in MSWM. Yogyakarta City suffers from an inability to cope with waste generation since the waste generation is increasing proportionally to the population growth with the rate of 1.61% each year approximately. The waste authority claims that 85% waste generated was collected although the record from landfill operator showed that approximately 218.5 ton/day from Yogyakarta city was collected in 2009 and 2010. It shows that LoS of collection was only 70% in 2009 and 2010 indicating that not all generated waste was transported to the landfill (Table 22).

Table 22. **Current conditions of MSWM in Yogyakarta based on data 2009/2010**

Parameter	Unit	Yogyakarta
Area	km²	32.5
Population (million)	people	468,000
Waste generation	tons day^{-1} kg cap^{-1} day^{-1}	313 0.67
Waste collection	tons day^{-1}	218.5
Total MSW Cost	Billion Rp $year^{-1}$	3.99
	Million US $ $year^{-1}$	0.42
	Rp cap^{-1} $year^{-1}$	8.45
	$ cap^{-1} $year^{-1}$	0.89
MSW income	billion Rp $year^{-1}$	1.8
	Million US $ $year^{-1}$	0.19
LoS on waste collection	%	70
Currency conversion: US $ 1 = Rp 9,500		

Source: Meidiana, 2011; YEB, 2010

Referring to the national standard for LoS on waste collection, this percentage represents adequate performance which is upon 60% as the minimum LoS on waste collection (MoSri, 2001). The deficit budget on MSWM is also the problem because the waste income mainly from waste retributions is much lower than the expenses for the waste management. In addition, the inferior condition of Bendo landfill causes environmental problems such as gas emission and leachate leak. Bendo landfill life is approaching to the end period and will be ended in 2012 as the maximum capacity is almost reached (YEB, 2008). The municipal solid waste (MSW) generation in Yogyakarta city was estimated about 313 tons/day in 2010. Furthermore, based on the daily waste disposal record at Bendo landfill, the average amount of waste transported to the landfill (2007-2010) was 394 tons/day (including partly of Sleman and Bantul County).

The disposal waste in Bendo landfill shows an increasing trend as the population increase. Table 23 shows the waste generation and waste from Yogyakarta city delivered to Bendo landfill from 2000-2010 and the prediction until 2012.

Table 23. Waste generated in Yogyakarta and delivered to Bendo Landfill between 2000-2012

Year	Waste generation [ton]	Waste disposal [ton]	growth rate [%]
2000	95,733,18	66,965,36	-
2001	97,460,67	68,173,74	1.8
2002	99,237,07	69,416,33	1.8
2003	101,045,99	70,681,67	1.8
2004	102,887,67	71,969,92	1.8
2005	104,848,35	73,341,42	1.9
2006	106,745,68	74,668,60	1.8
2007	108,674,33	76,017,69	1.8
2008	110,034,45	76,969,10	1.3
2009	111,479,85	77,980,15	1.3
2010	113,986,41	79,733,49	2.2
2011	115,445,43	80,754,08	1.3
2012	116,923,14	81,787,73	1.3

Source: (YEB, 2009; 2010)

The low waste generation per capita and waste cost per capita characterizes MSWM in Yogyakarta. The waste generation per capita in this city is below 1 kg/cap/day, while the cost for waste management per capita is not more than US$ 1.0/cap/year. As a comparison, other big cities in Indonesia like Jakarta and Bandung has also low waste generation amounts to 0.67 kg/cap/day and 0.59 kg/cap/day respectively (Damanhuri et al., 2009; H.Pasang et al., 2007). It affirms that the typical waste generation rate in developing countries is low as mentioned by Diaz et al., (1993).

High fraction of biodegradable waste characterizes the waste composition in Yogyakarta since the waste mainly comes from household. Meanwhile, plastics and paper has the less percentage afterwards followed by other smaller fractions such as glass, metal, textile, rubber, diapers, woods and inert (Table 24). Paper, garden waste and food waste comprising kitchen and biowaste from household belong to the materials which will decompose rapidly, while the remaining waste constituents belong to materials that will decompose slowly.

Table 24. Waste characteristic of Yogyakarta

Waste component	% weight
'Dry' stream combustibles	
Paper	5.65
Plastics	9.96
Other dry combustible	
Textiles	2.27
Rubber	0.32
Nappies/diapers	2.37
'Wet' stream combustible	
Kitchen waste	32.66
Garden waste	23.33
Organic waste	21.37
Wood	0.72
'Dry' Non-combustibles	
Glass	0.34
Metal	0.19
Inert	0.72

Source: (YEB, 2009)

The collected waste is mainly delivered to the landfill and only small fraction of the waste is treated using other methods such as recycling and composting. It is important to understand that the recycling in this context does not refer to an activity to change substances called waste to other new form of substances, but to an activity of reusing substances considered as waste either by direct self-reuse or by selling them to the informal waste collector such scavengers or waste traders. Zurbruegg (2002) identified that in developing countries the process of recycling took place from source to the end destination, landfill. In Indonesia, the process occurs also from household level up to landfill involving the informal waste collector. At household level, scavengers will separate, collect or buy the recyclable waste. At collection point, the waste is sorted by scavengers and sometimes by cleansing workers (Supriyadi et al., 2000). At landfill, scavengers sort the waste and sell it to the middle man. The same situation occurs also in Yogyakarta where the direct self-reuse is done in household level and waste selling activity is practiced in both household level and landfills. The waste selling activity involves not only scavengers, but also solid waste management workers. The selected waste is finally sold to other parties such as industries.

Beside landfill and recycling, composting is another waste treatment method which has been practiced in Yogyakarta since 2005. There are many possibilities to operate a composting center regarding to the local conditions. It can be a governmental initiative or a government-community partnership. In a governmental initiative, the local government has fully responsibility for operation, control, and maintenance of the composting plant. In a government-community partnership, the local government facilitates the infrastructure and equipment while the community is responsible for sustainability of the composting center (Damanhuri et al., 2009). In Yogyakarta, the composting center is a government-community partnership. There are 14,742 households in Yogyakarta which are involved in community-based-composting centers with the total capacity of 66.33 m^3/day or equal to 25.01 ton/day organic waste based on the typical loose food waste density proposed by Diaz, et. al. (1993) ranging between 353 - 401 kg/m^3. The current total capacity of waste composting center is about 10.33% of biowaste generated in Yogyakarta. The treatment process of the biowaste produces 22 m^3/day or 8.3 tons/day compost. If the capacity is increased yearly, there could be a significant waste reduction through composting. Therefore, the local government is targeting to increase the capacity per year by 2.7% from the current level (25.7 tons/day) which will produce more compost up to 8.5 tons/day. Though the increasing amount of waste composted in Yogyakarta, the landfill method is still the preference for the local government in treating the MSW.

The proximate and ultimate analysis is conducted to analyze the waste properties in Yogyakarta. Due to the absence of measurement in lab scale, the value for proximate and ultimate analysis is calculated by using the typical value of related properties proposed by Kaiser (1978). The proximate and ultimate analysis for waste component in Yogyakarta is shown in Table 25. The high percentage of wet stream combustible (77%) causes the moisture content of waste in Yogyakarta is relative high (61%). This is the nature of typical waste in developing countries which has high organic content (about 70%) and high moisture content (about 50%) (Diaz et al., 1993).

Furthermore, the LFG volumetric chemical composition is calculated using Equation 2 which predicts the chemical reaction occurred during the waste degradation process in the landfill. According to the values in Table 24, the LFG generated in Bendo landfill contains about CH_4 = 55.8%; CO_2 = 42.97%; and NH_3 = 1.23%.

Table 25. Ultimate and Proximate analysis of Waste Stream in Yogyakarta

Ultimate analysis		**Proximate analysis**	
Component	Composition [m%]	Component	Composition [m%]
Carbon	57.66	Moisture	61.40
Hydrogen	6.83	Volatile	32.55
Oxygen	29.87	Fixed carbon	4.41
Nitrogen	4.84	Ash	1.62
Sulphur	0.70		

The waste incineration is not the waste authority's priority for final waste treatment because it requires high initial cost for the plant. Besides, the value gained from the proximate analysis indicating that waste is not suitable for incineration since one of those values is outside the range value required for incineration proposed by Buekens and Patrick (1985) for sustainability of incineration (Figure 11). Implementation of incinerating method in such condition demands sustain auxiliary fuel which can increase the operational cost. Therefore, there are no scenarios proposed in this study which include incineration as an option for final waste treatment.

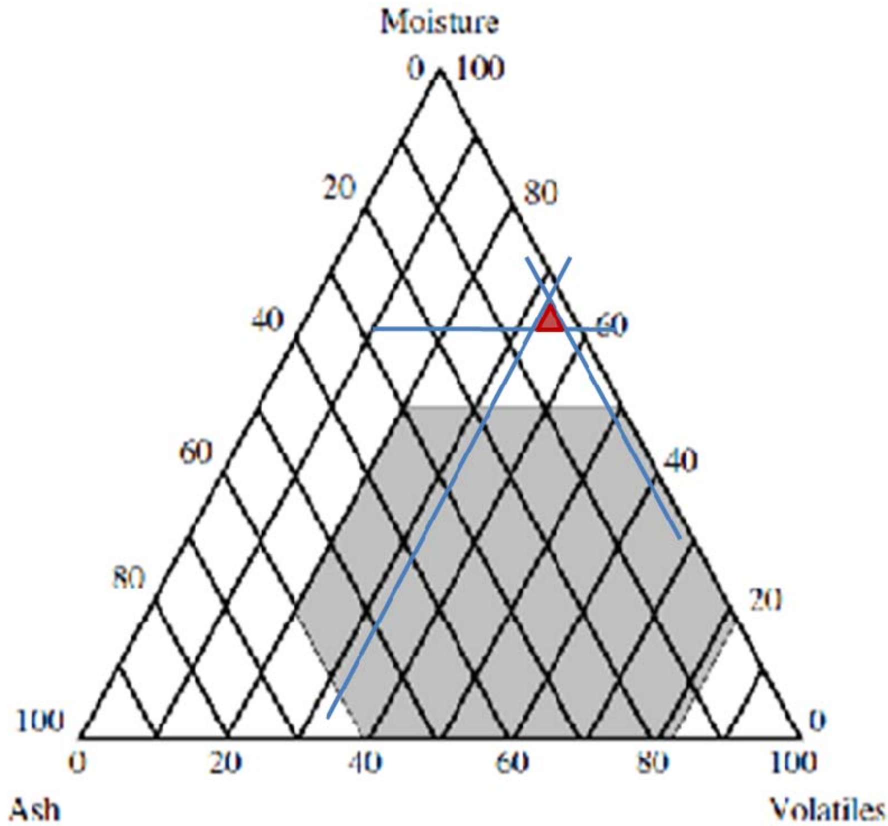


Figure 11. Existing Solid Waste Composition in Yogyakarta

6.2. Landfill Operation in Yogyakarta

6.2.1. Bendo Landfill (the old landfill)

Bendo Landfill is located in District Piyungan, Ngablak Village. The landfill was opened in 1993 and will be closed in 2012, replaced by a new final disposal site. Initially, the landfill was constructed in area which was distant from the settlement but there is now a settlement with the distance of about 0.7 km from the outer boundary of Bendo landfill (Figure 12). The total area of Bendo Landfill is about 12.5 ha with depths ranging from 1 meter approximately to 20 meters and divided into 3 zones (Figure 13). The Bendo Landfill accepts MSW from Yogyakarta, and two other counties, Sleman and Bantul and will have had the total waste capacity about 2.5 million ton by 2012.

Bendo landfill is owned, managed and operated by the local government. The waste delivered to the landfill is mixed waste from household and commercial without any treatments prior to the landfill. The emission from landfill is managed by using drainage and treatment pond for leachate and passive ventilation for landfill gas. Yet, only part of the site is equipped with passive ventilation. The usage of heavy equipment in landfill is mainly functioned for skipping, leveling and lifting up the waste. The operator of Bendo Landfill believe that they are operating a controlled landfill. However, the comparison study between the existing conditions and the landfill's criteria showed that neither controlled landfill nor sanitary landfill was practiced in Bendo landfill. Some measurements referring to the controlled landfill criteria from UNEP were implemented in field, but only partially. Therefore, the existing conditions are not sufficient to be considered as indicators for a controlled landfill (Meidiana, 2011). Some basic requirements for lining system, regular waste record, access road, or regular soil covering have not been fulfilled completely. Although the drainage system is available, there is leachate coming out from the waste bulk and puddling the landfill area including access road eliciting odor nuisance. Unpaved access road causes the dirt sticks to the truck tires and litters the roads passed by dump truck. Table 26 describes the current conditions of Bendo landfill which is claimed as a controlled landfill equipped by heavy equipment for waste treatment and applied zoning systems.

Deficit budget for the municipal solid waste management causes the unfavorable MSWM in Yogyakarta, especially in landfill operation such as inferior landfill infrastructure, fleet lack, broken equipment and short of maintenance. This situation brings about the landfill operator’s incapability in satisfying the basic requirement for less risky waste disposal method. The landfill operator can not fulfill the standard requirements of equipment for collection and transportation from Ministry of Settlement and Regional Infrastructure and for waste disposal in landfill from Ministry of Public Works (MoPW, 1994; MoSri, 2001). Bendo Landfill operator calculated that more certain heavy equipments are still required (YEB, 2009).

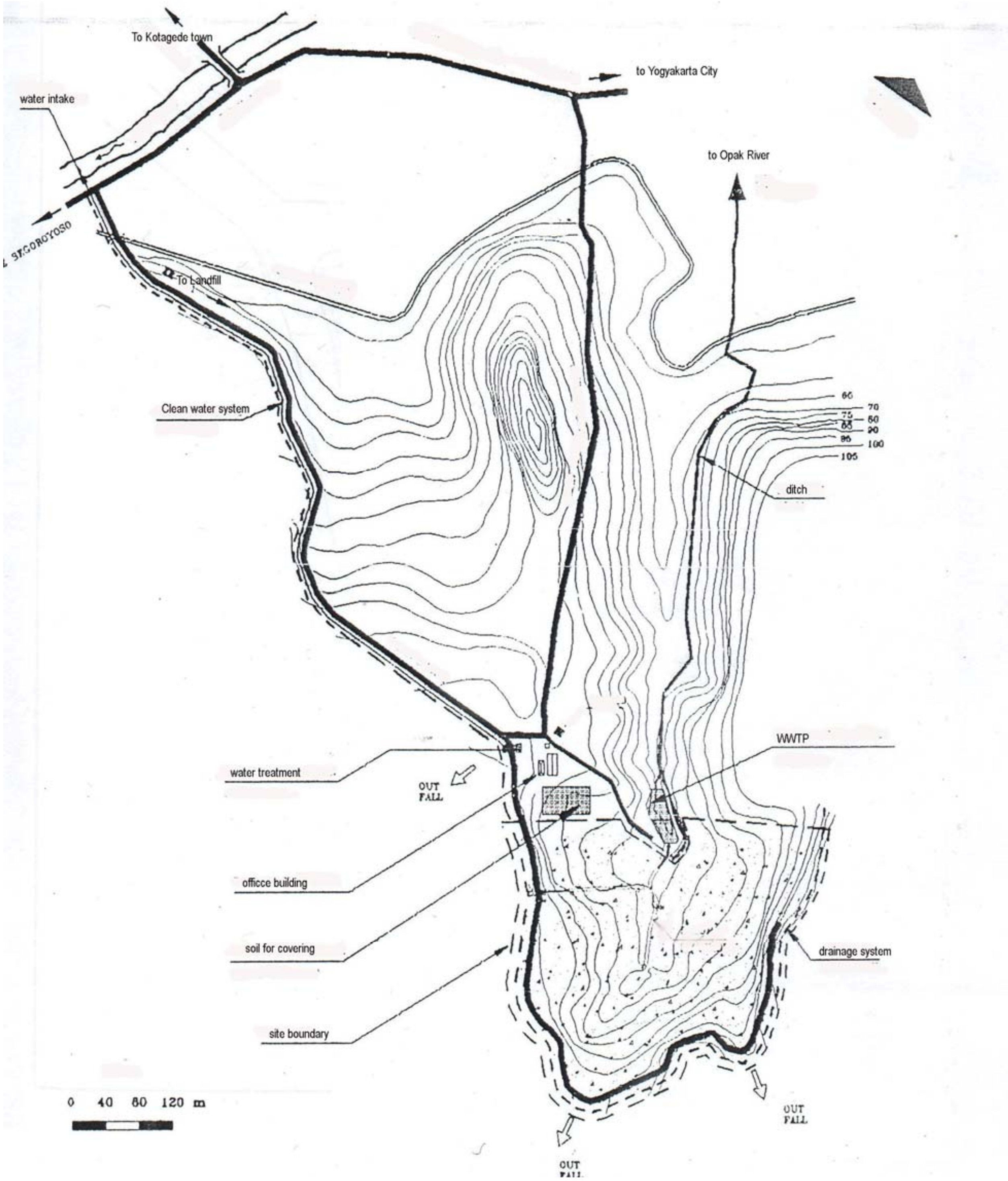


Figure 12. Site of Bendo Landfill

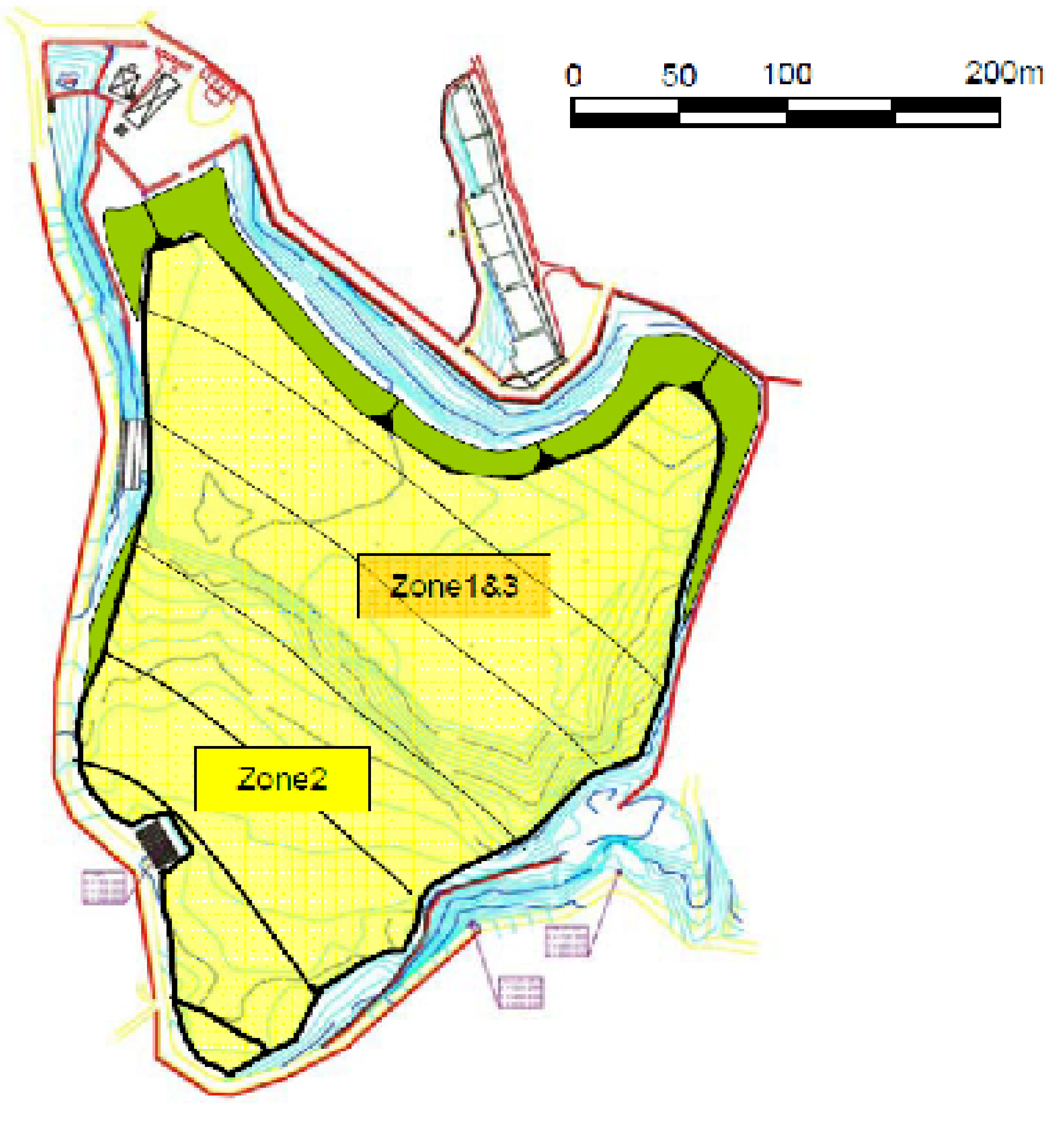


Figure 13. Layout of Bendo Landfill

Table 26. Evaluation of the existing landfill

Parameter	**Evaluation**
Site	
Type of landfill	Partially controlled landfill
Type of waste	Untreated mixed waste from household and commercial
Waste capacity	394 tons day^{-1}
Operator	Local government
Opening year	1993
Planned closing year	2012
Total area	12.5 (3 zones)
Distance to settlement	700 m
Future landfill sites	Near to the old landfill
Infrastructure and Equipment	
Liner	Impermeable layer
Leachate collection	Drainage canal system, 3 leachate treatment pond, and treatment 1 aeration facilities
LFG management	Passive ventilation (partially)
Access road maintenance	Limited. Asphalt
Fencing	Available
Equipment	1 office, 1 weigh bridge, 1 ware house, 2 bulldozers 1 excavators, 1 wheel loaders, 1 mini track loader
Operational	
Soil covering	Regularly but not daily
Waste compacting	Partially
Waste inputs	Lack of control, mixed waste
Record keeping	Partially basic record
Scavengers (registered)	400 scavengers

Source: Meidiana, 2011

The current MSWM condition in Yogyakarta implies that the target to implement a sanitary landfill in such inferior condition is likely improper solution. The capability of local government to operate sanitary landfill is questioned for high initial expenses, high investment, high operation and maintenance (M&O) cost, lack of resource sustainability such as finance, technology and capable human resources. Besides, many scavengers are depending on landfill for their income by separating and selling the waste from landfill. Pursuing the local government to implement high standardized landfill technology which does not allow the presence of scavengers in landfill area can also be problematic because hundreds of families will lose their income. This should be avoided by accommodating both situations in which the local governments can minimize the adverse environmental effect of impropriate landfill practices and keeping the scavengers in separating waste in landfill manageably. The waste selection prior to the landfill can reduce the waste amount and landfill gas (LFG) emission (Ranaweera , 2001, Komilis et al., 1999[a];1999[b]). Therefore, involving the scavengers in landfill can be an advantage for landfill operator in reducing the waste volume dumped in landfill contributing LFG emission decrease. The most relevant option for the new landfill is controlled landfill for some reasons proposed by Meidiana (2011). Constructing a controlled landfill required absolutely high expenditure. However, capital and operational cost of controlled landfill is lower than sanitary landfill.

As mentioned above, Bendo landfill accepts not only waste from Yogyakarta, but also from Sleman and Bantul County with the average percentage of 64%, 30% and 6% respectively. The percentage of waste from Sleman and Bantul do not reflect the LoS in both regions because the amount is only partial. The rest is delivered to other landfill in its own region. Figure 14 describes the amount of waste from three regions delivered to Bendo landfill which generally tends to increase.

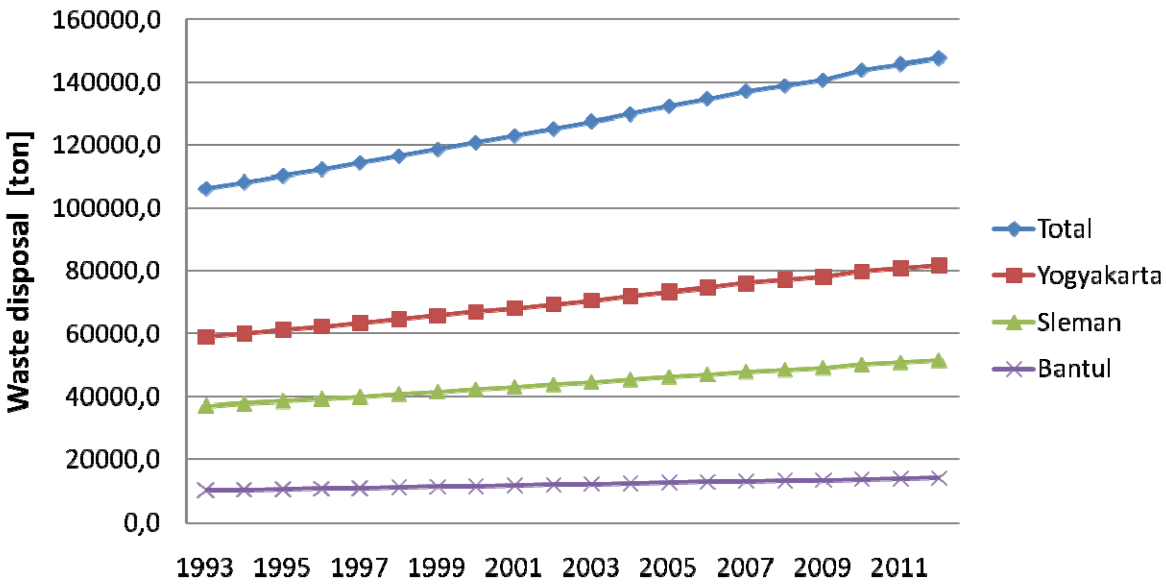


Figure 14 Waste delivered to Bendo Landfill

6.2.2. Waste reduction through scavengers

There are about 400 scavengers registered in Bendo landfill and sort saleable material such as plastics, papers, glass and metal. The activity of sorting and selling are done inside the landfill site. Based on the number of registered scavengers, there should be 200 respondents for the survey (5% sample error). However, during preliminary survey, it has been identified that only 45 scavengers can be chosen as respondents. Therefore, all 45 scavengers were objected to the questionnaires. The result showed that they are mostly between 26 and 35 years old (65%) and come from the surrounding villages (75%). Their activities occurred in the day time, beginning from early morning until afternoon where the fresh waste was recently discarded. Most scavengers (82%) work at least 8 hours per day and do scavenging as their main activities to earn money (58%). They sort the salable used material such as paper, metal, plastic and glass bottles. Weighing and selling the collected waste was conducted inside the landfill area. Most scavengers have income between US$ 1.58 and US$ 3.16 per day (87%) as shown in Figure 15.

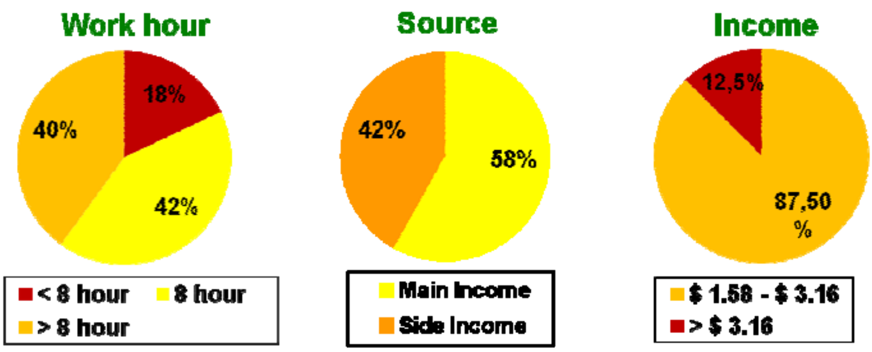


Figure 15. Data on Scavengers in Bendo Landfill

Some scavengers build also temporary shelter for staying. There is no restriction area and waste type for the scavengers. The mobility of heavy vehicles and trucks are disturbed and the scavengers endanger their life by working near to the vehicles and their health by direct contact to the mixed waste which could contain hazardous waste such as batteries, electrical equipments, lamp bulbs, possibly contaminated utilities i.e. knives or needles from medical waste.

The sorted material is weighed and each scavenger have to pay Rp. 1000 (US$ 0.1) per day for weighing fee. The collected materials will be sold to the middle man before it is transported and sold to the other parties, such as metal industries and used paper industries. Separation and collection process as well as weighing and selling activities occurred in landfill site. Figure 16 shows the role of scavengers in reducing the waste at Bendo landfill, while Figure 17 presents waste reduction conducted by the scavengers.

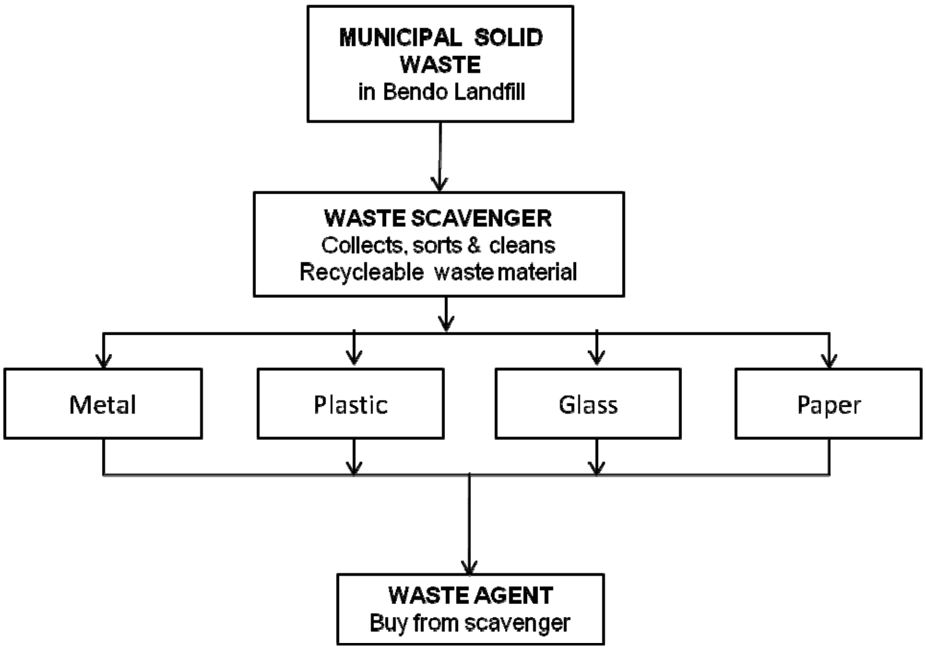


Figure 16. Role of Scavenger at Bendo Landfill

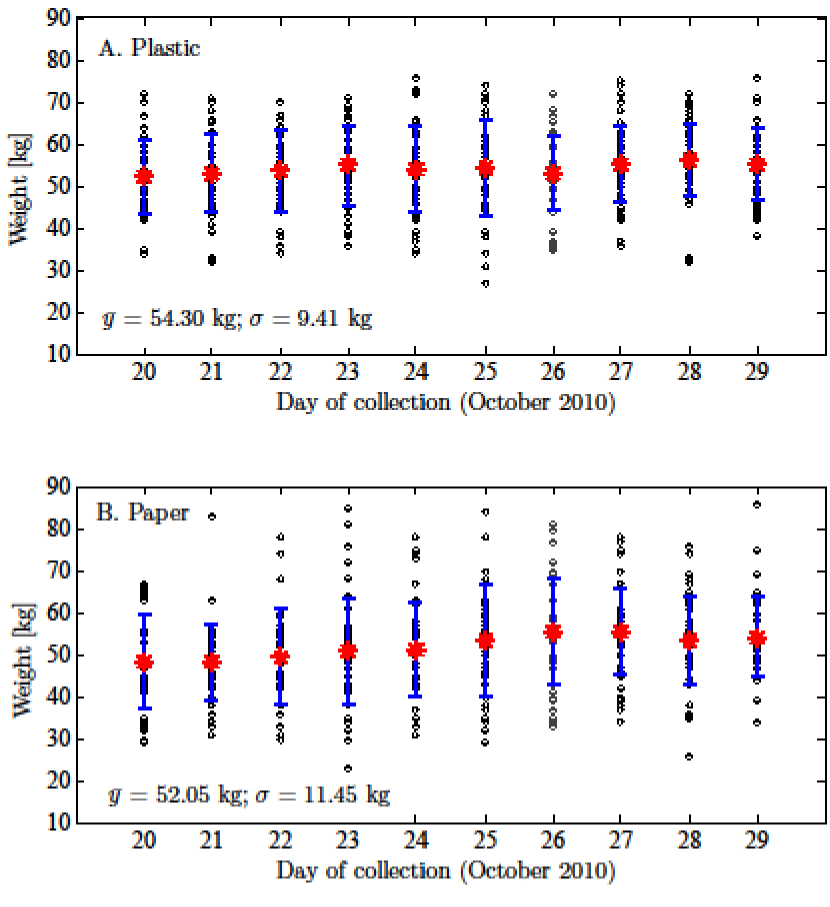


Figure 17. Waste sorting at Bendo Landfill

The amount of waste sorted by the scavengers is approximately 54.3 kg/cap/day and 52.05 kg/cap/day for plastics and paper respectively. The amount of glass and metal sorted from waste in Bendo landfill is very small during the observation which amount to 0.036 kg/cap/day and 0.004 kg/cap/day respectively. The value gained from the field survey is used as the reference to estimate the total waste reduction done by the scavengers in the new landfill. The waste reduction done by 45 samples is shown in Table 27, while the overall waste input and output in Municipality of Yogyakarta is described in Figure 18.

Table 27. Waste reduction at Bendo landfill

Component	Disposal [kg/day]	Reduction [kg/day]	Percentage [%]
Plastics	32,259.0	2,431.0	7.54
Paper	18,300.0	2,355.0	12.87
Glass	1,101.0	1.6	0.15
Metal	615.4	0.2	0.03

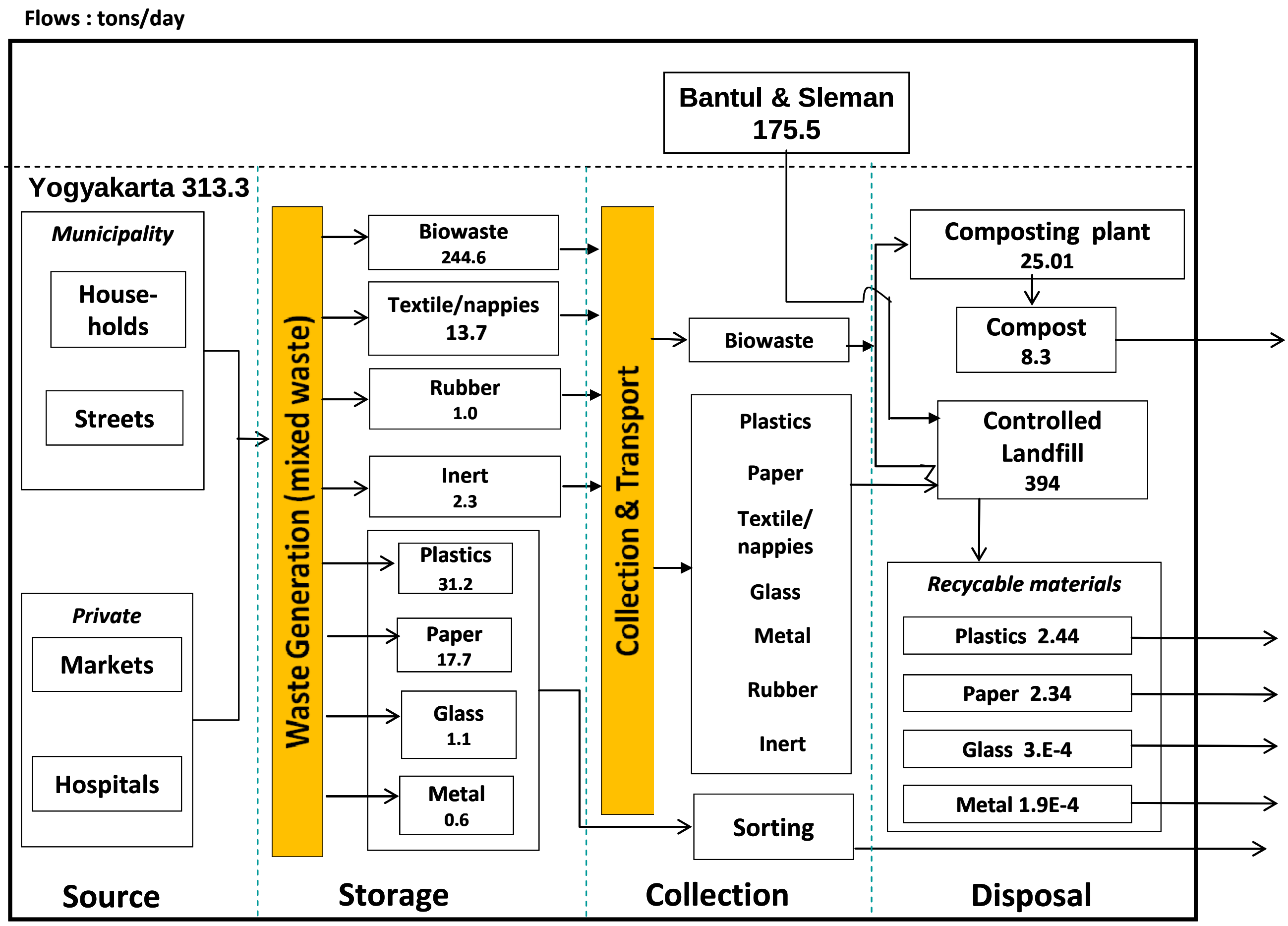


Figure 18. Waste stream in boundary system

6.3. Estimation of GHG emission from Bendo Landfill

For the estimation of methane emission from Bendo landfill, equations presented in Chapter 5 are used. The estimation is made for two conditions, namely with and without reduction (with and without measure). The waste reduction is done by the representative scavengers in landfill and by composting centers. The result shows that without waste reduction, the total methane emission from Bendo landfill (1994 – 2042) is about 1.34E+05 ton CH_4 or 2.81E+6 ton $CO_{2eq..}$ Figure 19 shows the methane emission from Bendo landfill if there are no measures in MSMW. This is the condition where there is no waste reduction through scavenging and composting.

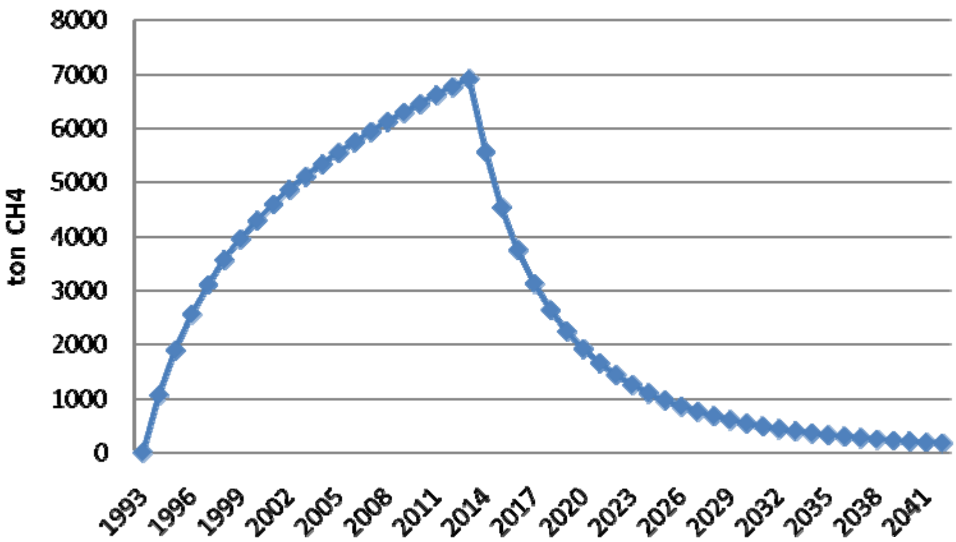


Figure 19. Methane Emission from Bendo Landfill without any measures

The degradation of rapidly decomposable fractions produce LFG with the higher rate compared to that of slowly decomposable fractions. The LFG production increases until the last year of the landfill life and decreases after the closure. In 2042, the methane generation is approaching to zero. The overall methane production trend of each waste constituent is drawn in Figure 20.

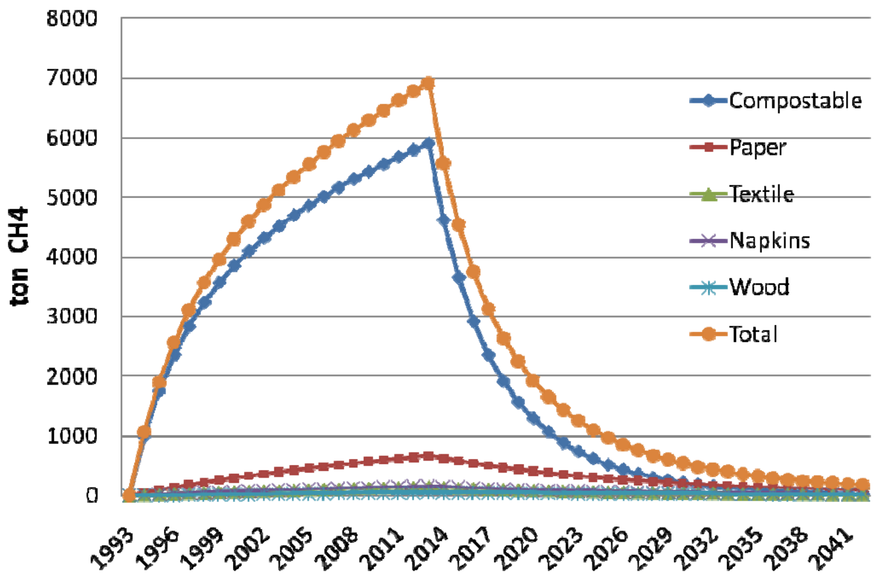


Figure 20. Methane Emission from each waste constituent in Bendo Landfill

If it is assumed that the current composting rate (10.33%) is maintained and the half of the registered scavengers (200 scavengers) work optimally, the amount of methane emitted will be 1.20E+05 ton CH_4 or 2.52E+06 ton CO_{2eq} . It is equal to 10.45% emission reduction from the condition without any measures. However, since there are only 45 scavengers in Bendo Landfill who work optimally, the methane emission will reduce to 1.25E+05 ton CH_4 or 2.6E+06 ton CO_{2eq}. It means there is about 6.72% emission reduction due to the current scavenging and composting activity. It is obvious that the involvement of 45 scavengers contribute the methane emission reduction in Bendo landfill. However, the reduction is relative low. The slight decrease of methane emission will occur if it is assumed that the half of the registered scavengers is optimally involved in scavenging (Figure 21). The same effect is also indicated in Figure 22 that neither the current nor the targeted composting rate has an important influence on methane emission reduction. A significant methane emission can be achieved if the composted waste has a higher percentage for example 50% as targeted by the local government.

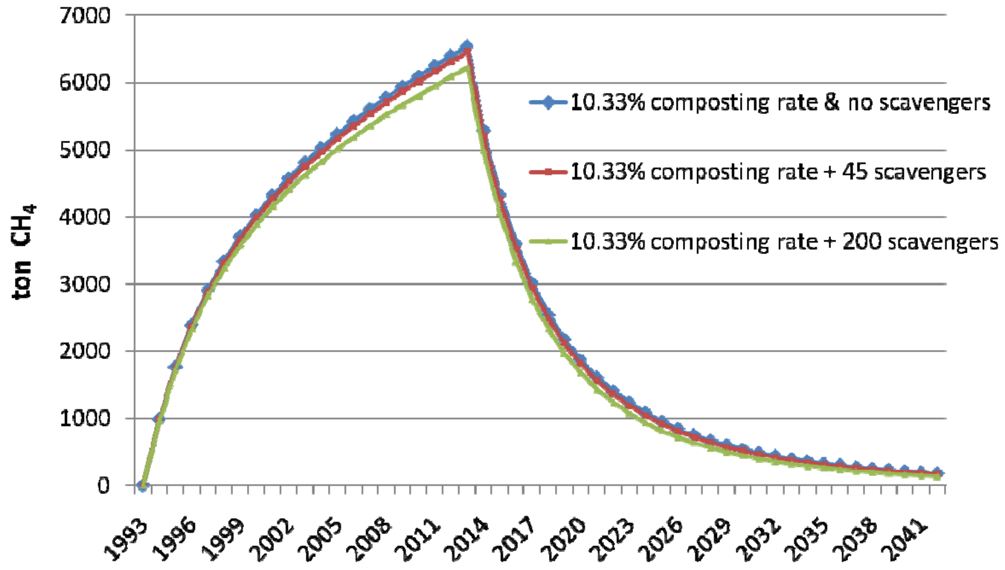


Figure 21. Impact of scavenging in reducing emission from Bendo Landfill

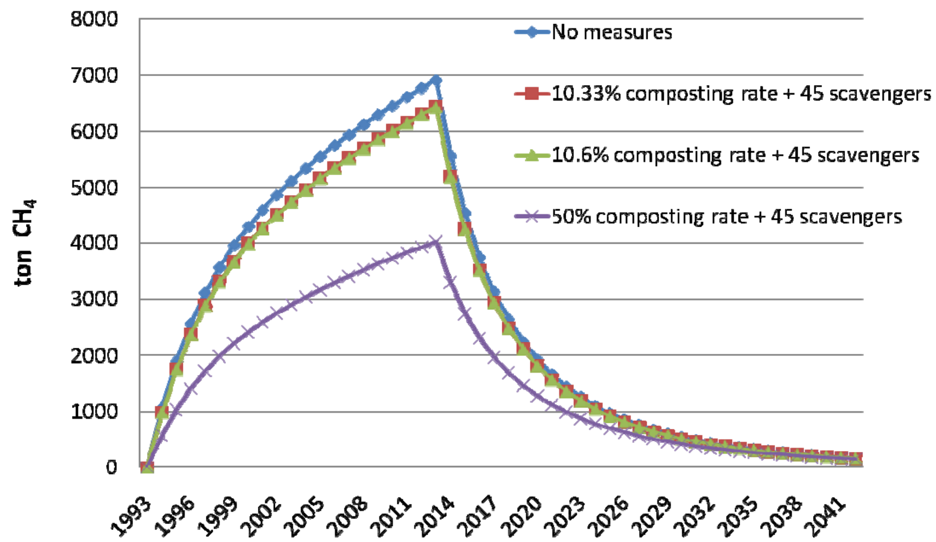


Figure 22. Impact of current and targeted composting rate on emission reduction from Bendo Landfill

The calculation indicates that increasing the amount of waste composted is more efficient to reduce methane emission from Bendo Landfill than increasing the number of scavengers.

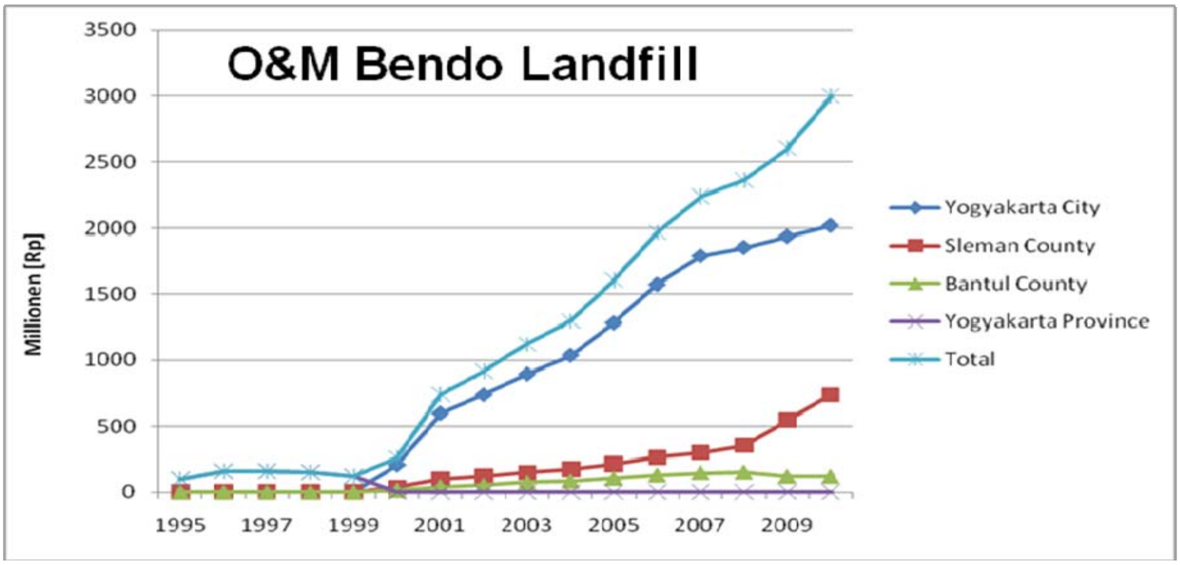
6.4. Economical aspect of MSWM in Yogyakarta

The decentralization in 1999 had implications in local income and expenses in many infrastructure developments including the waste sector. The local government should be self-sufficient in planning and managing their budget for MSWM and have to seek financial support for MSWM from local sources (Meidiana, 2010[a]). Most local governments in Indonesia have to finance MSWM by using their own budget. Local government of Yogyakarta also has to fully finance, manage and operate MSWM and there is no private participation. From 1995 until 2000, the O&M Bendo landfill is completely supported by province government, but after 2000 it was financed by local government. The capital and operational cost should be covered by local budget from regency/city and province. Operational and maintenance cost (O&M) for landfill is mostly provided by the Yogyakarta municipality, especially for the O&M Cost of Bendo landfill because waste disposed of in Bendo landfill mainly comes from waste sources located in Yogyakarta. Bantul and Sleman contributes only small amount as described in Table 28 as well as in Figure 23.

Table 28. Operational and Maintenance Cost of Bendo Landfill

Year	Yogyakarta City [Rp]	Sleman County [Rp]	Bantul County [Rp]	Yogyakarta Province [Rp]	Total [Rp]
95/96	-	-	-	100,000,000	100,000,000
96/97	-	-	-	162,788,000	162,788,000
97/98	-	-	-	161,551,000	161,551,000
98/99	-	-	-	154,135,000	154,135,000
99/00	-	-	-	125,000,000	125,000,000
2000	210,516,734	35,450,734	14,971,015	-	260,938,483
2001	599,315,100	100,923,900	42,620,600	-	742,859,600
2002	738,743,348	124,403,380	52,536,149	-	915,682,877
2003	895.340.064	150,774,056	74,882,580	-	1,120,996,700
2004	1,035,636,080	174,399,716	86,616,364	-	1,296,652,160
2005	1,281,383,021	215,784,182	107,171,679	-	1,604,338,882
2006	1,571,617,344	264,659,480	131,446,176	-	1,967,723,000
2007	1,789,138,080	301,289,850	149,639,070	-	2,240,067,000
2008	1,853,113,821	355,260,163	153,626,016	-	2,362,000,000
2009	1,934,953,538	546,725,355	121,221,107	-	2,602,900,000
2010	2,013,700,000	NA	NA	NA	NA

Source: (YEB, 2010)



Source: YEB, 2010

Figure 23 Operational and Maintenance Cost of Bendo Landfill

Generally, the O&M cost of Bendo landfill is increasing from 1995 to 2010. Before decentralization, the O&M cost is relative stagnant and was starting to increase significantly after that. There is generally a deficit in MSWM. The income from waste is lower than the expense. Table 29 describes the financial condition on MSWM in Yogyakarta.

Table 29. Income and Expenses of MSWM in Yogyakarta Municipality

Year	Income [Mio. Rp]		O&M Landfill [Mio. Rp]	MSWM Cost [Mio. Rp]	Coverage [%]
	Target	Realization			
2009	1,478	1,165	1,935	3,938	37.5
2010	1,719	1,782	2,017	4,019	44.4

Source: (YEB, 2010).

The local government could reach the income target from waste collection fee, as the determinant of income from waste management, in 2010 after unsuccessful effort in 2009. However, the waste management cost was still far beyond the income. The waste management cost which included the cost for collection, transportation and the O&M of Bendo landfill can not be fully covered from waste income. The local government had to find other income sources such as grants or soft loans from central government or international institutions which was not always successfully attained. The coverage of waste income is below 50% indicating that there was a deficit in waste management in Yogyakarta. The waste collection fee is the main source of the income from waste management in Yogyakarta, but can not cover the financial need because of low collection rate due to following factors (Meidiana, 2011);

- Poor rate payment and little effective enforcement.
- Collection fee is standardized according to house type, building function or electric power and do not related to the waste quantity produced. A household generating more waste may pay lower collection fee than another one producing less waste.
- Collection fee does not necessarily reflect the collection and disposal costs. There is no relationship between revenue collected and expenditure for waste since the collection fee is standardized rather than calculated.

The lack of budget is the main reason for the deprived MSWM. The budget for the waste management is lower than the required budget. The income in waste management mainly comes from the waste collection fee collected from the community. Still, it is lower than the existing cost meaning that the local government has to look for other sources to finance the waste management. Consequently, Bendo landfill tends to be operated as open dumping instead of a controlled landfill as claimed by the local government (Meidiana, 2011).

The involvement of scavengers in waste reduction in landfill was observed during 10 day survey. The result shows that the scavengers have reduced the waste tonnage disposed of in landfill and increased the added value of the waste because the waste is delivered as an input for other economy activities. They get also income from the waste picking activity. Table 30 shows the waste separation in Bendo landfill and the income from the recyclable materials, while Table 31 shows the income from waste management consisting income from scavenging and composting.

Table 30. Waste separation in Bendo landfill

Date	Plastics [kg]	Glass [kg]	Metal [kg]	Paper [kg]	Total [kg]
20 Oct 10	2,360.00	10.000	0.000	2,184.00	4,554.00
21 Oct '10	2,390.00	0.000	2.000	2,176.00	4,568.00
22 Oct '10	2,414.00	0.000	0.000	2,231.00	4,645.00
23 Oct '10	2,479.00	0.000	0.000	2,283.00	4,762.00
24 Oct '10	2,432.00	6.000	0.000	2,302.00	4,740.00
25 Oct '10	2,464.00	0.000	0.000	2,404.00	4,868.00
26 Oct '10	2,394.00	0.000	0.000	2,506.00	4,900.00
27 Oct '10	2,489.00	0.000	0.000	2,536.00	5,025.00
28 Oct '10	2,397.00	0.000	0.000	2,490.00	4,887.00
29 Oct '10	2,490.00	0.000	0.000	2,441.00	4,931.00
Average [kg/p/d]	54.02	0.0360	0.004	52.34.00	106,430.00
Total sample (25 scav-engers) [kg/d]	1,355.00	0.900	0.100	1,308.50	
Total 400 scavengers [kg/d]	21,608.00	14.220	1.780	20,936.00	

Scavengers in Bendo Landfill can sort the recyclable waste approximately 54.02 kg/day for plastic, 52.34 kg/day for paper, 0.036 kg/day for glass and very small amount for metal. If all scavengers (400 people) is assumed work, the amount of sorted waste is 42.56 t/day or about 13.14% of the total waste disposed. The involvement of 45 scavengers has reduced waste at rate of 1.48% of the total waste disposed.

Table 31. Income from waste sorting and composting centers in Yogyakarta

Materials	Mass [kg/p/d]	Price		Income [$/p/day]	Income [$/day]
		[Rp/kg]	[$/kg]		
From Bendo Landfill					
Plastics	54.30	200	0.02	1.14	
Glass	0.036	300	0.03	**0**	
Metal	0.004	250	0.03	**0**	
Paper	52.05	250	0.03	1.37	
Total				**2.65**	
Sub total sample(45 scavengers)					119.3
Sub total 200 scavengers					502
From Composting centers					
Compost [kg/d]	7,766	200	0.021		163.5

Each scavenger can earn about $ 2.51 in one day. Mainly, income comes from selling paper and plastic since these both waste can be found in Bendo landfill every day with abundant amount. Selling the metal and glass contributes very little income because metal can not be found every day and most glass ended in landfill is scattered glass which is worthless. Glass is valuable if it is still in the form of a container such as bottle or jar

6.5. The new landfill

As explained in Chapter 5, the new landfill will be constructed not so far from the old landfill. The landfill life is projected for 15 years initiated from 2013 until 2028. The new landfill will be operated as a controlled landfill. The assumptions conditioned to the old landfill are also applied to the new landfill.

6.5.1. Forecast MSW Generation and Disposal for the new landfill

There are factors which influence the waste generation in Yogyakarta. However, there is consensus that the important factors should be considered in making MSW generation projections are:

- Current city population
- Population growth rates, and

- Per capita waste generation, or
- Waste generation growth rate

The projection is initiated from 2013 using the number of population in 2012. The population and waste generation in the next years are calculated based on this value and with the average population growth rate of 1.51% and the average waste generation rate of 1.61%. The projection is made for 15 years as the landfill will be operated for 15 years (2013 – 2028). Once the population is calculated, the projection of waste generation can be calculated by multiplying it with per capita waste generation. The result is presented in Figure 24.

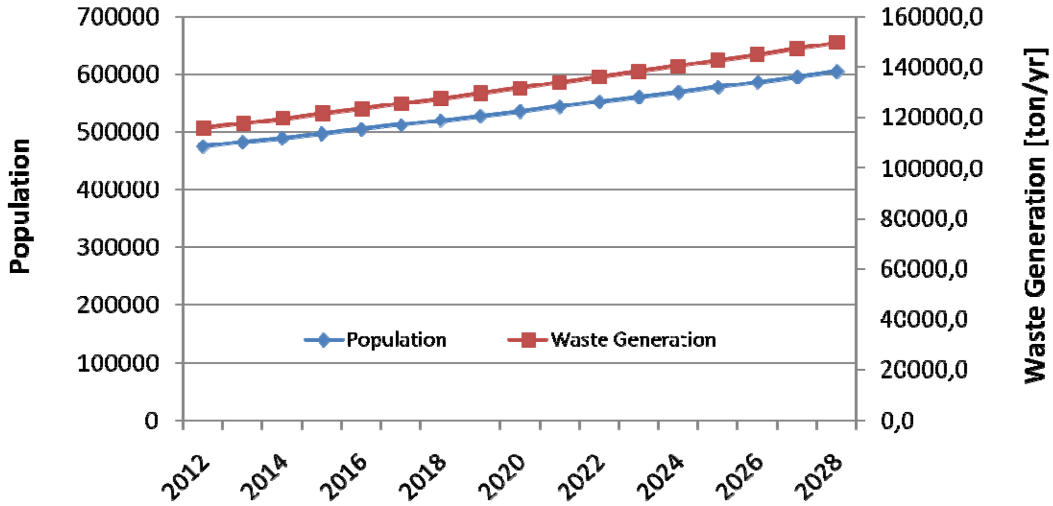


Figure 24. Projection of population and waste generation in Yogyakarta City

The waste generation is projected with the growth rate at 1.61%. The increase is proportional to the population increase. The average waste generation is 0.24 Mt/year. The projection of waste disposal in landfill is made referring to the landfill opening year in 2013 and duration for 15 years. Figure 25 shows the projection of waste disposed of in the new landfill.

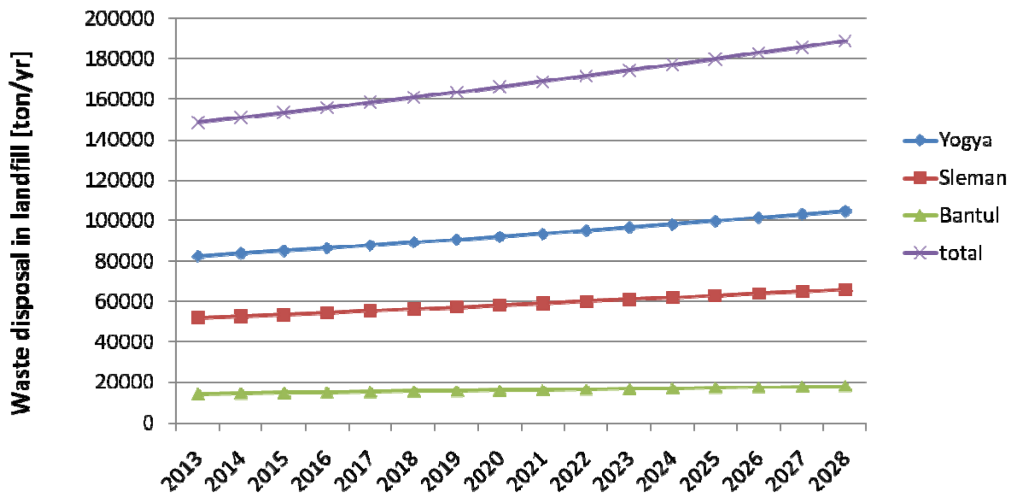


Figure 25. Waste disposal in the new landfill

Mostly waste come from Yogyakarta (64%), while the rest is from Sleman (30%) and Bantul (6%). In the initial year, the waste disposal from these three regions is 148,587 ton. At the last year waste disposal will be 188,811 ton. With the waste disposal growth of 1.61%, the new landfill will totally accept 2.7E+06 ton waste from 2013 until 2028 with the assumption of 70% LoS. If LoS is increased to be 85% (local target), the landfill will accept totally about 3.26E+06 ton waste.

6.5.2 Scenarios for final waste treatment method

There are three scenarios in this study to be compared. The scenario reflects the proper alternatives for final waste treatment in Yogyakarta. Each scenario comprises the MSWM stage including collection, landfilling process and composting. It is assumed that the landfill will be operated in 2013 and will accept waste from Yogyakarta City, partly of Sleman County and Bantul County until 2028. All the scenarios are assumed not to affect MSW generation meaning that the amounts and the composition of MSW are considerably the same in all scenarios. The implications of each scenario will be evaluated for its GWP and emergy indices. The GWP is calculated from methane and carbon dioxide emission from new landfill. Emission from other facilities of final waste treatment such as composting centre is not taken into account although it is inside the boundary system. In accordance to Lou (2009), aerobic decomposition in composting plant results CO_2 and H_2O. Methane can be also generated in anaerobic pockets within a compost pile due to the heterogenous nature of compost pile (Bogner, et.al., 2007; Brown, 2007). Nevertheless, some studies showed that the majority of methane emission oxidies to CO2 in aerobic pockets and near the surface of the compost pile, so that methane emission can be neglegted (Brown, 2004; Zeman, et.al., 2002).

The emergy values is gained from the calculation of emergy input and output within the boundary of landfill site and composting center. The emergy value of each scenario is then analyzed using emergy indices. The methane generation calculation is done with the assumption that methane will be generated for 47 years (2013 – 2060).

6.5.2.1. Scenario 0: Baseline scenario

Baseline scenario is a reference scenario and assumes that there is no change in the future waste management in Yogyakarta. According to the calculation in the previous sub chapter, 70% of MSW was treated in landfill and 10.33% of biowaste is treated in community based composting centers. The composting capacity increases though the constant rate because of the higher average amount of waste collected from 2013 – 2028. There is about 26.8 m^3/day or 36.8 t/day biowastes treated. Waste separation is done by 45 scavengers as the optimal current scavenging activity. It is assumed that they work 8 hours/day from Monday until Friday with the average waste sorting capacity for paper, plastic, glass and metal is 53.34 kg/cap/day, 54.02 kg/cap/day, 0.036 kg/cap/day and 0.004 kg/cap/day respectively. The waste reduction through scavenging is kept constant at 12.87% and 7.54% for paper and plastic respectively.

Calculation of methane emission using Equation 7 – 11 estimate that there will be 1.32E+05 ton CH_4 or 2.78E+06 ton CO_{2eq} emitted from the new landfill during inventory years from 2013 until 2060 if there are no changes in final waste treatment method. Without waste reduction, the total methane emission is approximately about 3.26E+06 ton CO_{2eq} with LoS of 70%. It means the current practice in waste treatment (scavenging and composting) has reduced the total methane emission about 4.8E+05 ton CO_{2eq} or about 14.71% from total emission in case there is no waste reduction. Figure 26 describes the methane emission from the new landfill during its operational time based on baseline scenario.

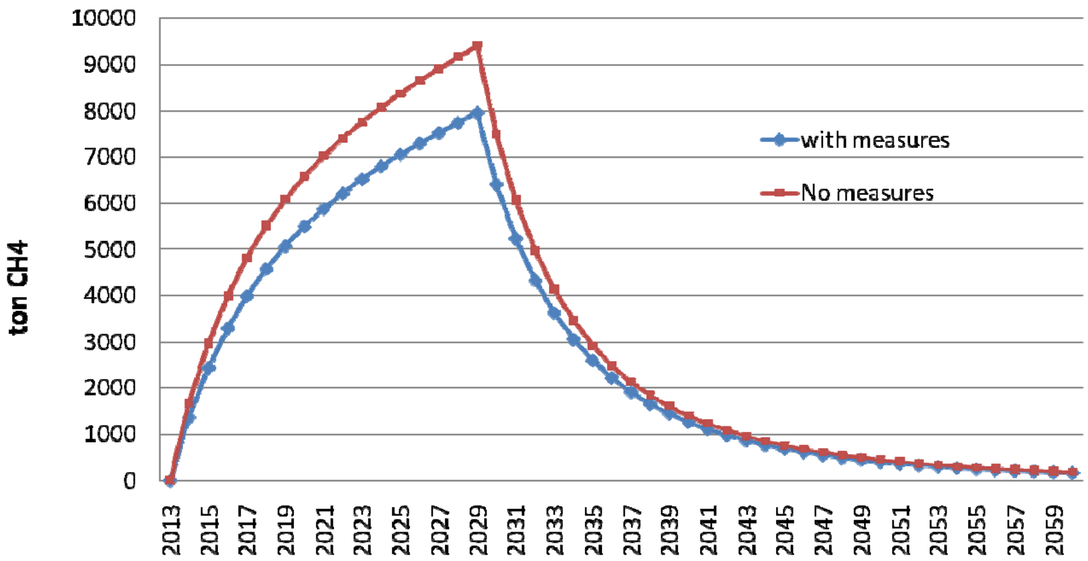


Figure 26. Methane emission from the new landfill based on Scenario 0

6.5.2.2. Scenario 1: LoS Improvement scenario

As the local government claims that the LoS of collection is 85%, Scenario 1 assumes that LoS will be increased to be 85% meaning that waste volume collected will be more. The composting rate will be increased, sum up to 50% to reduce the waste volume delivered to the landfill. 50% is the target of the local government to increase composting rate at the end of year 2011 (Zudianto, 2011). Due to this increase, the daily capacity of composting centers will be 230.5 ton/day or almost six fold increase compared to the base case which is 37 ton/day. The assumption of increase capacity makes sense as there is abundant organic waste and human resources. The composting centers use manual techniques requires no high investment for the added resources input.

In landfill, 45 scavengers will separate the recyclable materials. Due to the increase LoS, the total amount of the waste collected will increase from 2.69E+06 tons to 3.26E+06 tons. The total amount of methane emission from the new landfill is about 1.02E+05 tons CH_4 or 2.16E+06 tons CO_{2eq}. Figure 27 describes the methane emission from the new landfill during its operational time based on Scenario 1.

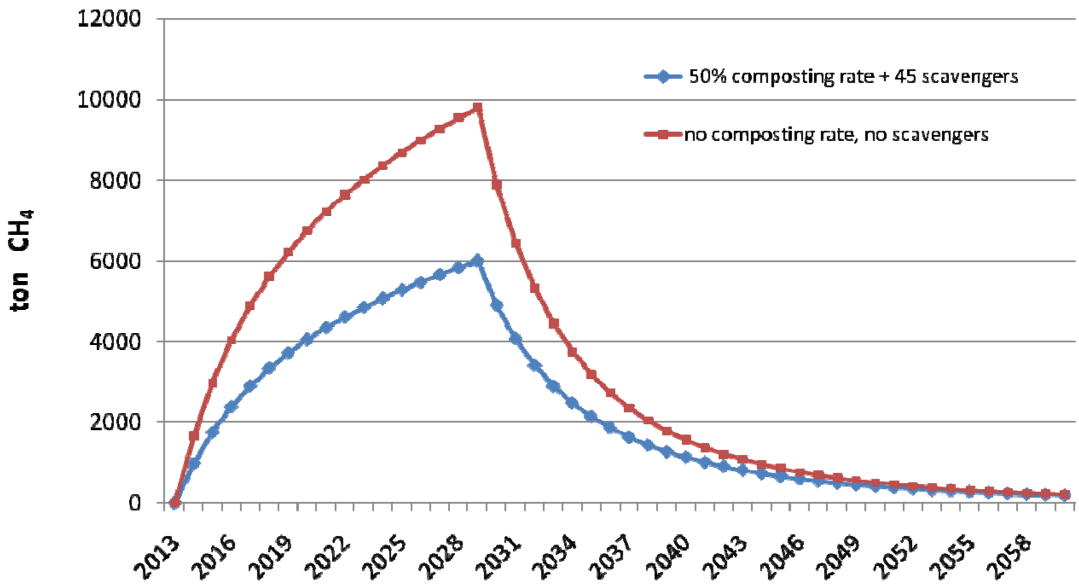


Figure 27. Methane emission from the new landfill based on Scenario 1

6.5.2.3. Scenario 2: LFG Flaring Scenario

In Scenario 2, scavenging is allowed only in certain area within the landfill site, where LFG collection system is not constructed. It assumed that 200 scavengers will work to separate the recyclable materials. There will be frequent compaction and soil covering (once a month). The composting rate is set to be 50% and the LoS is assumed to be 85%.

The average collection system costs for landfills with flaring system is assumed based on the value proposed by Jaramillo and Matthews (2005) which includes flaring costs. The initial costs for the collection system is 628,000 $ and the O&M is US $ 89,000/yr. In Scenario 2, the methane emission from landfill will be 2,002,004 ton CO_2eq as showed in Figure 28. The composting rate is the same as in the Scenario 1. Therefore, composting capacity is 230.5 ton/day and the compost production is 76 tons/day

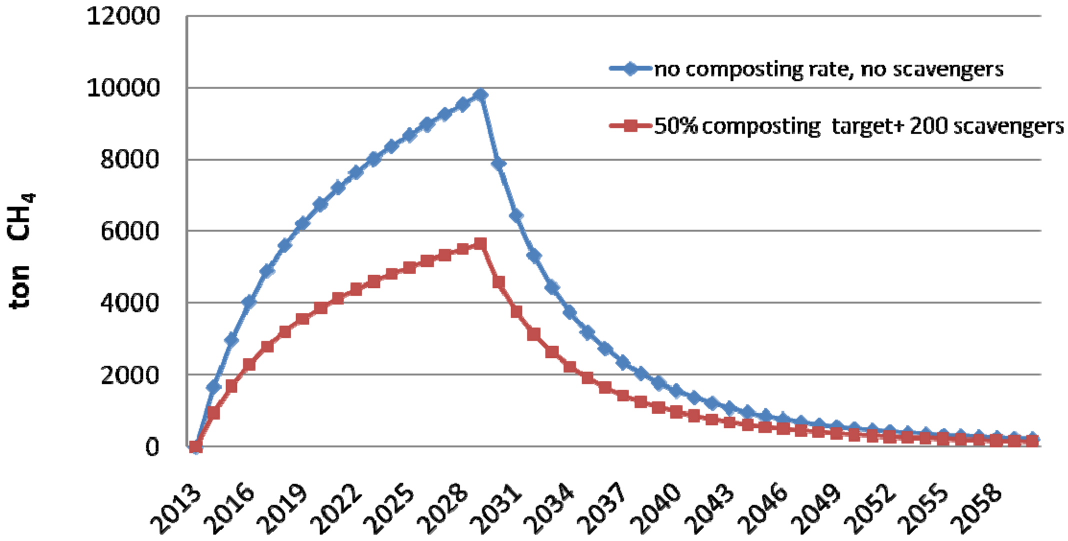


Figure 28. Methane emission from the new landfill based on Scenario 2

The global warming potential (GWP in CO_2 equivalent) and specific GHG effect from the scenarios have been compared to the worst condition if there are no waste reduction and the LoS of collection is 85%. The comparison is made to give the overview that the change of the organic content in landfilled waste changes the global warming potential and specific GHG effect more significantly than that of paper content.

Scenario 0 and Scenario 1 emits more methane and have higher GWP than Scenario 2. Scenario 2 generates the lowest total emission because of the significant reduction of organic waste transported to the landfill and the construction of flaring system in the landfill. Flaring system has converted CH_4 into CO_2 through combustion. The specific GHG emission is calculated for each Scenario and the result shows that in Scenario 0, one ton disposed waste generate the highest specific GHG emission (1,049 kg CO_2eq /t MSW collected). The lowest specific emission is produced in Scenario 2 (613 kg CO_2eq/t MSW collected) as illustrated in Figure 29. The result indicates that Scenario 2 generates the least emission. The graphic implies that the change of composting rate affects the specific GHG emission more considerably than the change of scavenging rate. Scenario 1 and 2 can reduce the impact of GHG on environment about 22% and 28% respectively from the base scenario. The 50% organic waste reduction through composting has decreased the emission considerably.

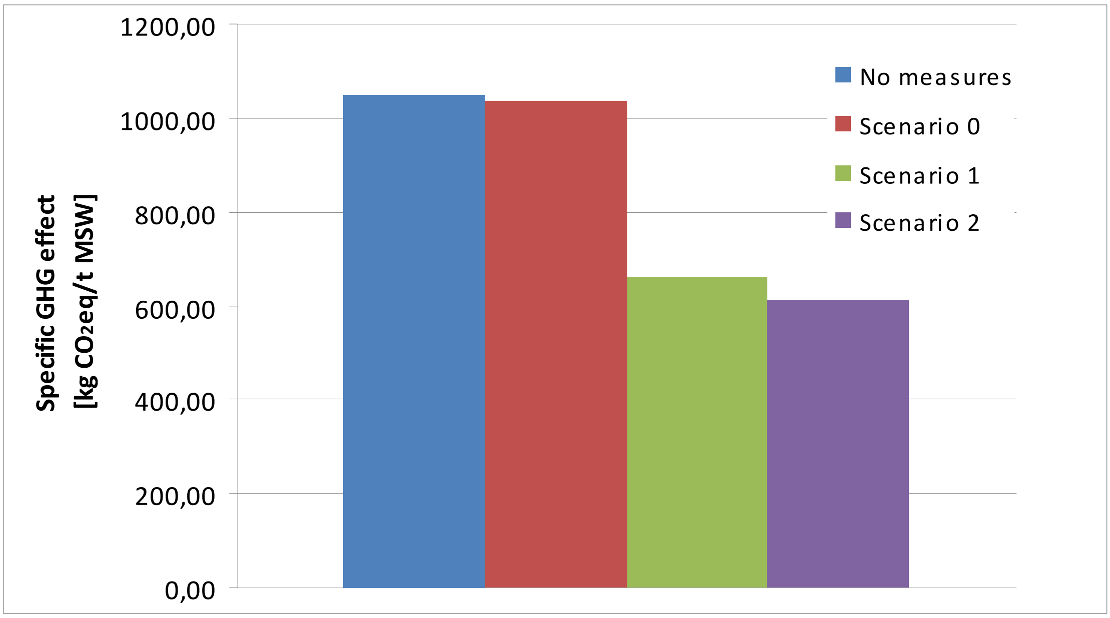


Figure 29. Specific GHG emission comparison of each scenario

The comparison between the three scenarios in terms of GWP demonstrates that the scavenging and composting play role in waste reduction which brings the GWP reduction. Yet, the change of scavenging rate influence less significant than that of composting rate. Therefore, the combination of both measures is the best result as it can minimize the methane emission effectively. Generally, the result of the comparison of all scenarios is summarized in the Table 32 and Table 33.

Table 32. Summary of comparison during landfill life

Parameter	No measures	Scenario 0	Scenario 1	Scenario 2
Input parameters				
LoS collection [%]	85	70	85	85
No. of scavengers	0	45	45	200
Composting rate [%]	0	10.33	50	50
Total waste collected [ton]	3,263,023	2,687,195	3,263,023	3,263,023
Output parameters				
CH_4 emission [ton CO_2eq]	3,423,478	2,780,848	2,158,676	2,002,004
CO_2 emission [ton]	2,636,323	2,141,452	1,662,337	1,541,687
Flaring (50% collection) [ton CO_2]	-	-	-	1,001,002
Specific GHG effect [kg CO_2eq/ ton MSW collected]	1,049	1,034	661	613

Table 33 Summary of comparison for composting

Parameter	Existing (2010)	Scenario 0	Scenario 1	Scenario 2
Input parameters				
LoS collection [%]	70	70	85	85
Composting rate [%]	0	10.33	50	50
Daily collection [ton/d]	313	460	595	595
Organic waste [ton/d]	25.01	36.76	230.5	230.5
Organic waste [g/yr]	9.13E+09	1,43E+10	8,41E+10	8,41E+10
Output parameters				
Compost [ton/d]	8.25	12.9	76.1	76.1
Compost [g/yr]	3.01E+09	4.72E+09	2.78E+10	2.78E+10

6.5.3 Emergy analysis for the scenarios of final waste treatment in Yogyakarta.

The following steps are undertaken for the emergy analysis during the study:

1. Identification of the boundaries of the investigated system
2. Making of emergy system diagram. The emergy diagram describes the emergy flows into and out from the system in the form of material and energy transfers. Hence, it is necessary to identify all variables involved in the process. The main stages, the inputs, the output and the relations between individual elements are presented in emergy system diagram.
3. Calculation of matter and energy flows supporting the scenario. All inputs in the system are divided into two groups; renewable resources and non renewable resources. Each group is subdivided into free resource and purchased resources. The calculation of emergy in waste treatment is conducted using Equations 14, 15 and 16. The amount of the available emergy (exergy) is calculated based on the primary and secondary data. The detailed calculation of the available emergy is attached in the appendices
4. Conversion of input matter and energy flows into solar emergy Joules (seJ) by using suitable transformities, recalculated to the new baseline for biosphere (total emergy driving the biosphere: 15.84×10^{24} seJ year) (Brown and Ulgiati, 2004[a]; Campbell et al, 2004; Odum 2000)
5. Calculation of the emergy cost for safe disposal of one unit of waste (seJ/g).

The values of transformity are presented in the table of emergy evaluation. Some of them are calculated and some are taken from emergy data bases available in the literature.

6.5.3.1. Overview of models and flow summary

The final solid waste treatment system in Yogyakarta City is the boundary. The input for the system is waste, renewable/non renewable resources and services. The input flow of waste assumed to have zero emergy content because mixed waste is not considered as a desired product of human activities, but instead an unavoidable and undesired emission (CO_2, CH_4 and other pollutants) (Ulgiati et al., 2007). For the waste material just stored in the landfill, there is no reason for assigning it a transformity.

The outputs are the products produced during the process including also the good/services that are sold in the market. Figure 30 illustrates the waste emergy system diagram for final solid waste treatment in Yogyakarta according to Odum's rules. Compost is the outputs of the process, while emission and recyclable materials are the by products Compost is produced in composting centers, emission is generated from waste degradation process in landfill, and recyclable materials are sorted and sold by scavengers. The emission as a product is not calculated in the emergy analysis since it has been calculated separately. The emission from the system is confined to be methane and carbon dioxide emission. The stages involved in final solid waste treatment are collection, waste disposal in landfill and waste treatment in composting centers. Collection includes collection in household level (door to door collection) and collection in community level (transfer point collection). The organic waste collected is distributed to the composting centers spread out in Yogyakarta City. The rest will be transported to the new landfill. The more detailed emergy flow system diagram is presented in each scenario.

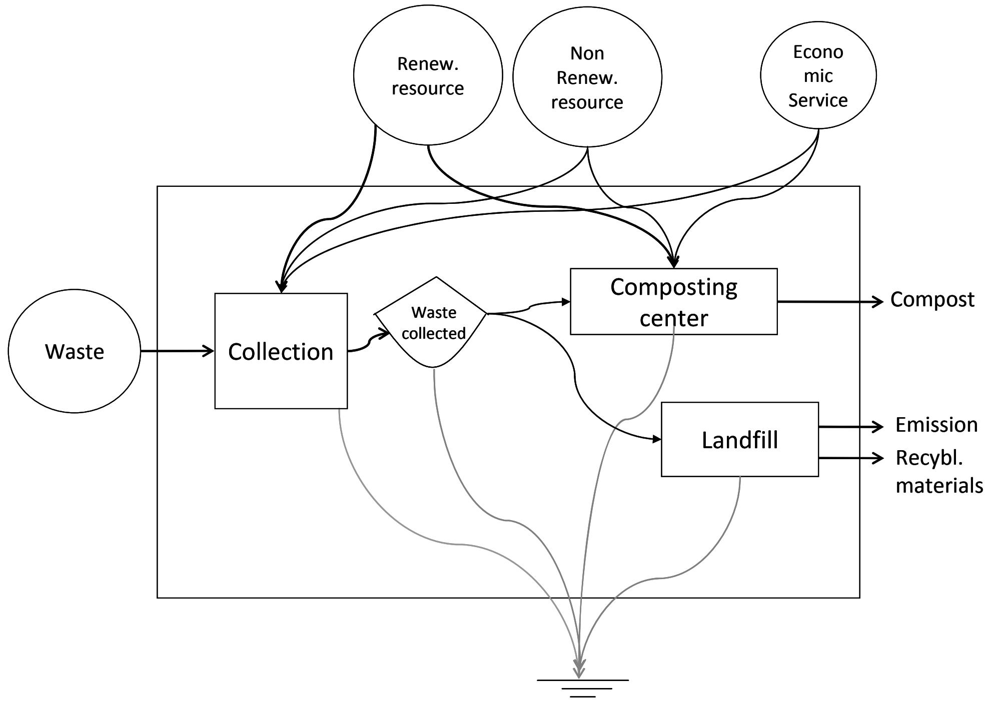


Figure 30. General emergy system diagram of MSW in Yogyakarta City

The emergy benefits of each scenario are represented by the arrow to the market. Compost and recyclable material from landfill is the emergy benefit for all scenarios. The emergy flow system diagram for Scenario 0 and Scenario 1 is presented in Figure 31. Meanwhile, Figure 32 describes the emergy flow system diagram for Scenario 2. Scenario 0 and Scenario 1 have the same emergy diagram since the process is the same only the amount of the emergy is different caused by the difference inputs. In these figures, the phases including collection, treatment and disposal are shown. Collection is conducted in household level through door to door (DtD) collection and in community level through transfer point collection (TP). In landfilling process, emission is the by-product which is not taken into consideration for the emergy analysis. It has been separately calculated in GWP analysis. Methane emission and carbon dioxide emission is calculated during 47 years as the methane generation is approaching to very small quantity thereafter. Other gases produced from anaerobic process are not considered here as the amount is very little compared to the main LFGs and assumed to be negligible in terms of emergy costs. Surely, the insertion of these little amount would have effect on increasing emergy investment. The emergy benefit from landfilling process is the money flown into the landfill coming from the scavenging activities. The emergy recovery from composting is calculated by transforming the monetary values from the compost selling into emergy units, using the emergy-to-money ratio in Indonesia, 2.06E+13 seJ/$ (Univ. Florida, 2000). As the study is limited to the emission from the landfill, the emission from the WWTP and composting process will not be considered.

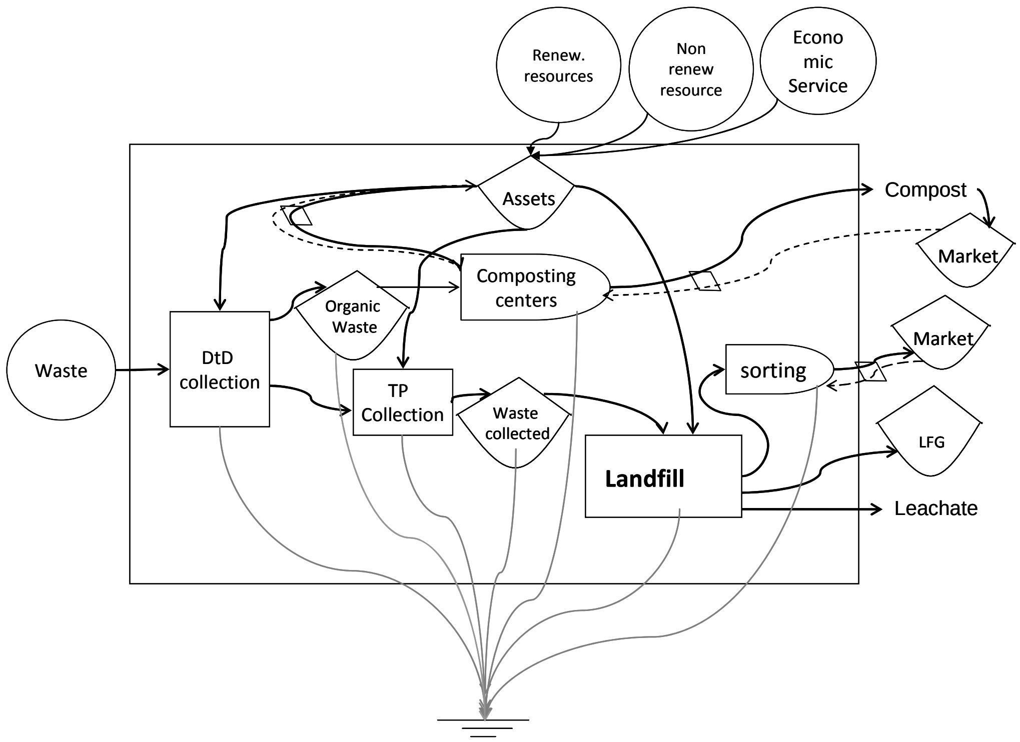


Figure 31. Emergy system diagram of Scenario 0 and Scenario 1

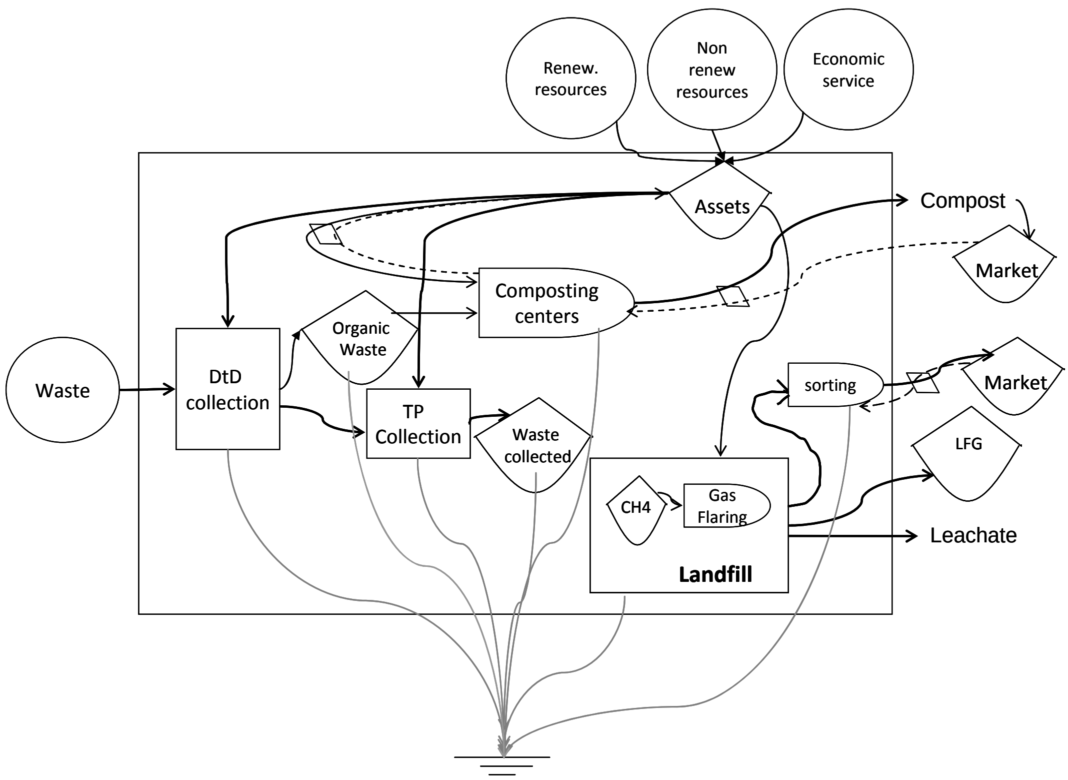


Figure 32. The emergy system diagram of Scenario 2

After describing the emergy flow in the diagram, the calculation of the total emergy is conducted and presented in table of emergy. Table 34, 35 and 36 present the results of the emergy values performed in each scenario. The transformities used in this section are based on the value from literatures and from the study self. Each scenario is evaluated for its emergy which is divided into three main parts, namely emergy from the MSW collection, landfilling process and composting. It can be summarized that in terms of emergy investment, the results of the emergy analysis demonstrate a similar trend for all scenarios although the values vary. Landfill requires the highest emergy investment to all scenarios with the percentage ranges between 92% - 97%. Collection ranks in the second place with the percentage of 3% - 9%, while composting invests the smallest percentage of emergy which is less than 1% (Figure 33 – 35).

Table 34 and Figure 33 (Scenario 0) shows that Scenario 0 contributes total solar emergy of 3.30E+23 seJ/yr and needs total emergy investment of 1.84E+12 seJ/gMSW. Most emergy is invested in landfill. The emergy recovery is gained from scavenging in landfill and composting which contributes 4.02E+08 seJ/gMSW. The emergy inputs in Scenario 0 are the lowest. This is because less amount of disposed waste requires less quantity of equipment, fuel, labor and other capital causing less input of emergy.

Table 35 and Figure 34 (Scenario 1) illustrates that the process contributes total solar emergy of 3.78E+23 seJ/yr and requires emergy investment of 1.74E+12 seJ/gMSW. The emergy investment is mainly from landfill (96.4%). The emergy recovery in Scenario 1 is also from income of scavengers and compost selling. The emergy investment in Scenario 1 is the lowest indicating that Scenario 1 has the lowest cost among two others. It means that under Scenario 1, the cost should be provided to manage one unit mass of MSW is lower compared to other scenarios. In this case, the more input in waste treated leading to the more efficiency in waste treatment.

Table 36 and Figure 35 (Scenario 2) demonstrates that the total solar emergy is 3.97E+23 seJ/yr which is the highest value compared to other scenarios. The emergy investment in Scenario 2 is 1.83E+12 seJ/gMSW. The result indicates that the emergy investment depends not only on the emergy input but also the effectiveness of waste collection. In this case, Scenario 1 and 2 with the higher LoS of Collection (85%) and higher emergy inputs than Scenario 0 can reduce the emergy investment because along with the higher emergy inputs, the effectiveness of waste collection is increasing. The more adequate equipment and labor raise the capability of the waste authority to collect the waste leading to lower emergy investment.

Table 34. Emergy flows supporting the landfill life cycle of the scenario 0

No	Item	Unit	Amount	Transformity [seJ/unit]	References	Solar emergy [seJ/year]	Emergy investment [sej/g MSW treated]
Renewable local resources (RR)							
1	Air (composting)	g	1.96E+08	5.16E+07	Wang et. al. (2006)	1.01E+16	5.64E+04
2	Scavengers (landfill)	J	1.42E+11	4.63E+06	this study	6.57E+17	3.67E+06
						6.67E+17	**3.72E+06**
Renewable local resources purchased (RP)							
3	Water (landfill)	g	1.10E+10	6.64E+05	Wang et. al (2006)	**7.27E+15**	**4.06E+04**
Non renewable resources in collection process purchased (NP)							
4	Handcart	g	1.74E+07	5.91E+09	Buranakarn (1998)	1.73E+17	9.67E+05
5	Vehicles	J	951E+11	7.76E+09	Odum (1997)	1.24E+22	6.92E+10
6	Fuel	J	2.73E+12	6.60E+04	Odum, (1996)	3.03E+17	1.69E+06
7	Water	g	3.65E+09	6.64E+05	Wang et. al (2006)	2.42E+15	1.35E+04
8	Labor	J	2.90E+12	4.63E+06	this study	1.34E+19	7.50E+07
9	Management cost	$	9.50E+05	2.06E+13	Univ. Florida (2011)	1.96E+19	1.09E+08
						1.24E+22	**6.94E+10**
Non renewable free (NR)							
10	Material for plant construction	g	9.66E+13	1.68E+09	Odum, (1996)	2.73E+23	1.52E+12
11	Material for final covering	g	6.21E+12	1.68E+09	Odum, (1996)	1.75E+22	9.79E+10
						3.15E+23	**1.76E+12**
Non renewable input to plant construction, waste management and processing purchased (NP)							
12	Material for plant construction (steel)	g	1.85E+11	4.13E+09	Buranakarn (1998)	1.28E+21	7.15E+09
13	Fuel	J	1.35E+12	6.60E+04	Odum, (1996)	1.50E+17	8.37E+05
14	Electricity	J	3.03E+10	1.60E+05	Odum, (2000)	4.85E+15	2.71E+04
15	Vehicles	J	8.21E+10	7.76E+09	Odum (1997)	1.07E+21	5.98E+09
16	Labor	J	6.31E+09	4.63E+06	this study	2.92E+16	1.63E+05
						2.35E+21	**1.31E+10**
Economic services (NP)							
17	Total cost of landfill plant	$	3.37E+06	2.06E+13	Univ. Florida (2000)	6.94E+19	3.87E+08
18	Annual O&M cost incl. Labor.	$	1.75E+06	2.06E+13	Univ. Florida (2000)	3.60E+19	2.01E+08
						1.05E+20	**5.89E+08**

	Average annual disposal of waste	g	1.79E+11				
	Output						
	Total main LFG (CO_2 & CH_4)	**4,92E+12**	g CO_2eq	4.80E+04		2.36E+17	
	Income of scavengers	**4,35E+04**	$	2.06E+13		8.96E+17	5.00E+06
Non renewable input to DtD collection purchased (NP)							
19	Handcart	g	1.99E+03	5.91E+09	Buranakarn (1998)	1.98E+13	1.38E+03
20	Labor	J	6.31E+09	4.63E+06	this study	2.92E+16	2.04E+06
						2.92E+16	**2.04E+06**
Non renewable input to composting plant construction, management and processing purchased (NP)							
21	Electricity	J	1.91E+10	1.60E+05	Odum, (2000)	3.05E+15	2.13E+05
22	Fuel	J	3.25E+10	6.60E+04	Odum (1996)	3.60E+15	2.52E+05
23	Labor	J	1.83E+12	4.63E+06	this study	8.45E+18	5.90E+08
						8.46E+18	**5.91E+08**
Economic services (NP)							
24	Investment cost	$	3.45E+03	2.06E+13	Univ. Florida (2000)	7.11E+16	4.96E+06
25	Management cost	$	5.94E+05	2.06E+13	Univ. Florida (2000)	1.22E+19	8.55E+08
						1.23E+19	**8.60E+08**
	Annual waste treated	g	1.43E+10	1.39E+11			
	Output						
	Compost	g	**4.72E+09**	4.41E+09			
	Compost Price (Rp 1000/kg)	$/g	0.000105				
	Income	**$**	**4.97E+05**	**2.06E+13**		**1,02E+19**	**7,16E+08**
	Total solar emergy (1-25)	**3.30E+23**	**seJ/yr**				
	Collection	**6.94E+10**	seJ/gMSW	3.76%			
	Treatment in Landfill	**1.77E+12**	seJ/gMSW	96.2%			
	Composting	**1.45E+09**	seJ/gMSW	<1%			
	Total solar emergy investment	**1.84E+12**	seJ/gMSW				

Table 35. Emergy flows supporting the landfill life cycle of the scenario 1

No	Item	Unit	Amount	Transformity [seJ/unit]	References	Solar emergy [seJ/year]	Emergy investment [sej/gMSW treated]
Renewable local resources free (RR)							
1	Air (composting)	g	9.48E+08	5.16E+07	Wang et. Al. (2006)	4.89E+16	2.25E+05
2	Scavengers (landfill)	J	1.42E+11	4.63E+06	this study	6.57E+17	3.02E+06
						7.06E+17	**3.25E+06**
Renewable local resources purchased (RP)							
3	Water	g	1.10E+10	6.64E+05	Wang et. al (2006)	**7.27E+15**	**3.34E+04**
Non renewable resources in collection process purchased (NP)							
4	Handcart	g	1.86E+07	5.91E+09	Buranakarn (1998)	1.84E+17	8.47E+05
5	Vehicles	J	1.05E+12	7.76E+09	Odum (1997)	1.36E+22	6.27E+10
6	Fuel	J	3.14E+12	6.60E+04	Odum, (1996)	3.48E+17	1.60E+06
7	Water	g	5.48E+09	6.64E+05	Wang et. al (2006)	3.64E+15	1.67E+04
8	Labor	J	3.36E+12	4.63E+06	this study	1.56E+19	7.15E+07
9	Management cost	$	1.10E+06	2.06E+13	Univ. Florida (2000)	2.27E+19	1.04E+08
						1.37E+22	**6.29E+10**
Non renewable resources in landfill free (NR)							
10	Material for plant construction	g	9.66E+13	1.68E+09	Odum, (1996)	2.73E+23	1.25E+12
11	Material for regular and final covering	g	3.11E+13	1.68E+09	Odum, (1996)	8.77E+22	4.03E+11
						3.60E+23	**1.66E+12**
Non renewable input to plant construction, waste management and processing purchased (NP)							
12	Material for plant construction (steel)	g	185E+11	4.13E+09	Buranakarn (1998)	1.28E+21	5.88E+09
13	Fuel	J	4.06E+12	6.60E+04	Odum, (1996)	4.50E+17	2.07E+06
14	Electricity	J	3.03E+10	1.60E+05	Odum, (2000)	4.85E+15	2.23E+04
15	Vehicles	J	2.08E+11	7.76E+09	Odum (1997)	2.71E+21	1.25E+10
16	Labor	J	6.31E+09	4.63E+06	this study	2.92E+16	1.34E+05
						3.99E+21	**1.84E+10**
Economic services (NP)							
17	Total cost of landfill plant	$	3.37E+06	2.06E+13	Univ. Florida (2000)	6.94E+19	3.19E+08
18	Annual O&M cost incl. Labor.	$	1.94E+06	2.06E+13	Univ. Florida (2000)	4.00E+19	1.84E+08
						1.09E+20	**5.03E+08**

	Annual disposal of waste	g	2.18E+11				
	Output						
	Total main LFG (CO_2 & CH_4)	g CO_2 eq	3.82E+12				
	Income of scavengers	$	4.35E+04	8.69E+18		3.78E+23	
Non renewable input to DtD collection purchased (NP)							
19	Handcart	g	3.98E+03	5.91E+09	Buranakarn (1998)	3.96E+13	1.82E+02
20	Labor	J	1.26E+10	2.62E+05	this study	6.14E+17	2.82E+06
						6.14E+17	**2.82E+06**
Non renewable input to composting plant construction, management and processing purchased (NP)							
21	Electricity		1.91E+10	1.60E+05	Odum, (2000)	3.05E+15	1.40E+04
22	Fuel		5.42E+10	6.60E+04	Odum (1996)	6.01E+15	2.76E+04
23	Labor		2.34E+12	4.63E+06	this study	1.08E+19	4.99E+07
						1.09E+19	**4.99E+07**
Economic services (NP)							
24	Investment cost	$	3.45E+03	2.06E+13	Univ. Florida (2000)	7.11E+16	3.27E+05
25	Management cost	$	7.65E+05	2.06E+13	Univ. Florida (2000)	1.57E+19	7.24E+07
						1.58E+19	**7.27E+07**
	Annual waste treated	g	8.41E+10				
	Output						
	Compost	g	2.78E+10	9.85E+08			
	Compost Price (Rp 1000/kg)	$/g	1.05E-04	**2.06E+13**		**6.02E+19**	
	Income	$	2,92E+06				
	Total solar emergy (1-25)	**3.78E+23**	seJ/yr				
	Collection	**6.29E+10**	sej/gMSW	3.62%			
	Treatment in Landfill	**1.68E+12**	sej/gMSW	96.4%			
	Composting	**1.26E+08**	sej/gMSW	<1%			
	Total solar emergy investment	**1.74E+12**	sej/gMSW				

Table 36. Emergy flows supporting the landfill life cycle of the scenario 2

No	Item	Unit	Amount	Transformity [seJ/unit]	References	Solar emergy [seJ/year]	Emergy investment [seJ/g MSW treated]
Renewable local resources (RR)							
1	Air (composting)	g	9.48E+08	5.16E+07	Wang et. al. (2006)	4.89E+16	2.25E+05
2	Scavengers (landfill)	J	6.31E+11	4.63E+06	this study	2.92E+18	1.34E+07
						2.97E+18	**1,36E+07**
Renewable local resources (RP)							
3	Water	g	1.10E+10	6.64E+05	Wang et. Al (2006)	**7.27E+15**	**3,34E+04**
Non renewable resources in collection process (NP)							
4	Handcart	g	1.86E+07	5.91E+09	Buranakarn (1998)	1.84E+17	8.47E+05
5	Vehicles	J	2.50E+12	7.76E+09	Odum (1998)	3.26E+22	1.50E+11
6	Fuel	J	3.14E+12	6.60E+04	Odum, (1996)	3.48E+17	1.60E+06
7	Water	g	5.48E+09	6.64E+05	Wang et. Al (2006)	3.64E+15	1.67E+04
8	Labor	J	3.36E+12	4.63E+06	this study	1.56E+19	7.15E+07
9	Management cost	$	1.10E+06	2.06E+13	Univ. Florida (2000)	2.27E+19	1.04E+08
						3.27E+22	**1.50E+11**
Non renewable resources free (NR)							
10	Material for plant construction	g	9.66E+13	1.68E+09	Odum, (1996)	2.73E+23	1.25E+12
11	Material for regular and final covering	g	3.11E+13	1.68E+09	Odum, (1996)	8.77E+22	4.03E+11
						3.60E+23	**1.66E+12**
Non renewable input to plant construction, waste management and processing							
12	Material for plant construction (steel)	g	1.85E+11	4.13E+09	Buranakarn (1998)	1.28E+21	5.88E+09
13	Fuel	J	4.06E+12	6.60E+04	Odum, (1996)	4.50E+17	2.07E+06
14	Electricity	J	3.03E+10	1.60E+05	Odum, (2000)	4.85E+15	2.23E+04
15	Vehicles	J	2.08E+11	7.76E+09	Odum (1997)	2.71E+21	1.25E+10
16	Labor	J	6.31E+09	4.63E+06	this study	2.92E+16	1.34E+05
						3.99E+21	**1.84E+10**
Economic services							
17	Total cost of landfill plant	$	4.00E+06	2.06E+13	Univ. Florida (2000)	8.23E+19	3.78E+08
18	Annual O&M cost incl. Labor.	$	1.92E+06	2.06E+13	Univ. Florida (2000)	3.96E+19	1.82E+08
						1.22E+20	**5.61E+08**

	Annual disposal of waste	g	2.18E+11				
	Output						
	Total main LFG (CO_2 & CH_4)	g CO_2 eq	3.54E+12	4.80E+04		2.36E+17	
	Income of scavengers	$	8.70E+06	4.56E+16		3.97E+23	
Non renewable input to DtD collection							
19	Handcart	g	3.98E+03	5.91E+09	Buranakarn (1998)	3.96E+13	1.82E+02
20	Labor	J	1.26E+10	2.62E+05	this study	6.14E+17	2.82E+06
						6.14E+17	**2.82E+06**
Non renewable input to composting plant construction, management and processing							
21	Electricity		1.91E+10	1.60E+05	Odum, (2000)	3.05E+15	1.40E+04
22	Fuel		5.42E+10	6.60E+04	Odum (1996)	6.01E+15	2.76E+04
23	Labor		2.34E+12	4.63E+06	this study	1.08E+19	4.99E+07
						1.09E+19	**4.99E+07**
Economic services							
24	Investment cost	$	3.45E+03	2.06E+13	Univ. Florida (2000)	7.11E+16	3.27E+05
25	Management cost	$	7.65E+05	2.06E+13	Univ. Florida (2000)	1.57E+19	7.24E+07
						1.58E+19	**7.27E+07**
	Annual waste treated	g	8.41E+10				
					Total	**3.97E+23**	**1.83E+12**
	Output						
	Compost	2.78E+10	g	9,85E+08			
	Compost Price (Rp 1000/kg)	1.05E-04	$/g				
	Income	2.92E+06	$	2,06E+13		**6,02E+19**	
	Total solar emergy (1-25)	**3.97E+23**	**sej/yr**				
	Collection	**1.50E+11**	sej/gMSW	8.23%			
	Treatment in Landfill	**1.68E+12**	sej/gMSW	91.8%			
	Composting	**1.26E+08**	sej/gMSW	<1%			
	Total solar emergy investment	**1.83E+12**	sej/gMSW				

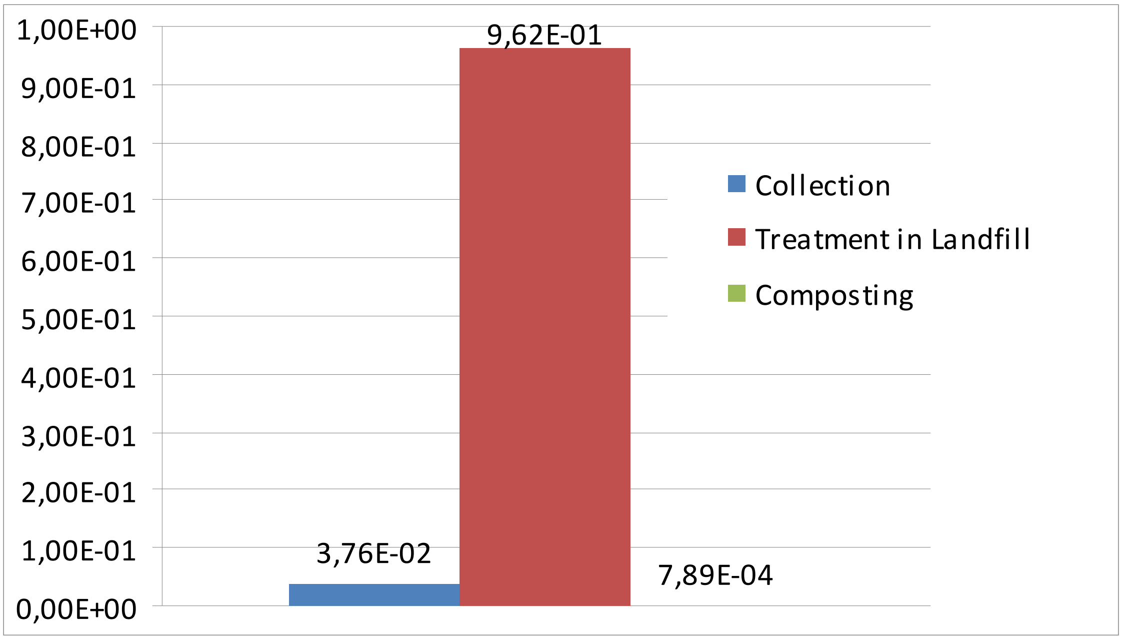


Figure 33. Share of emergy investment in Scenario 0

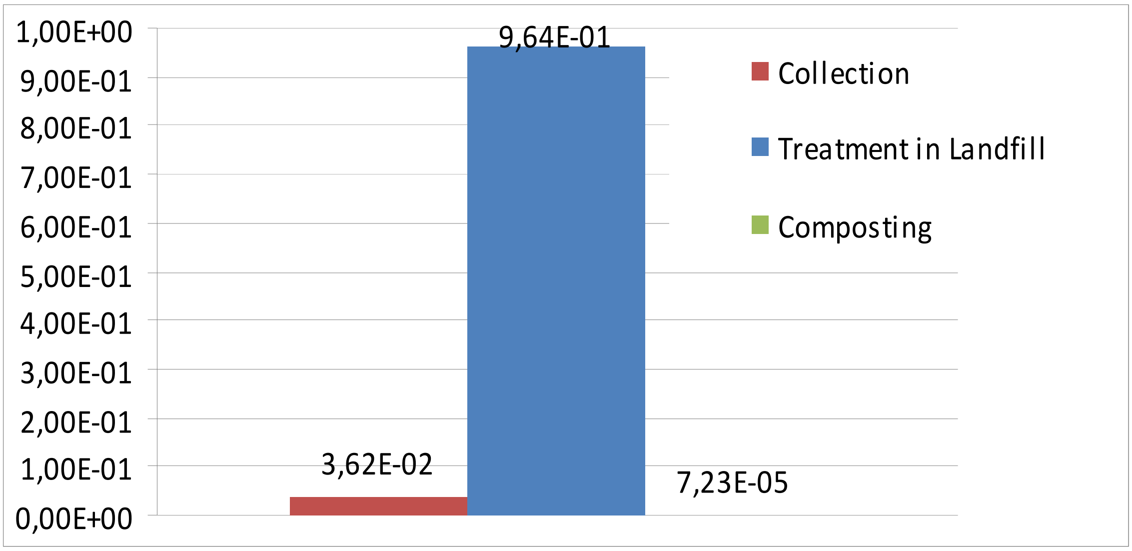


Figure 34. Share of emergy investment in Scenario 1

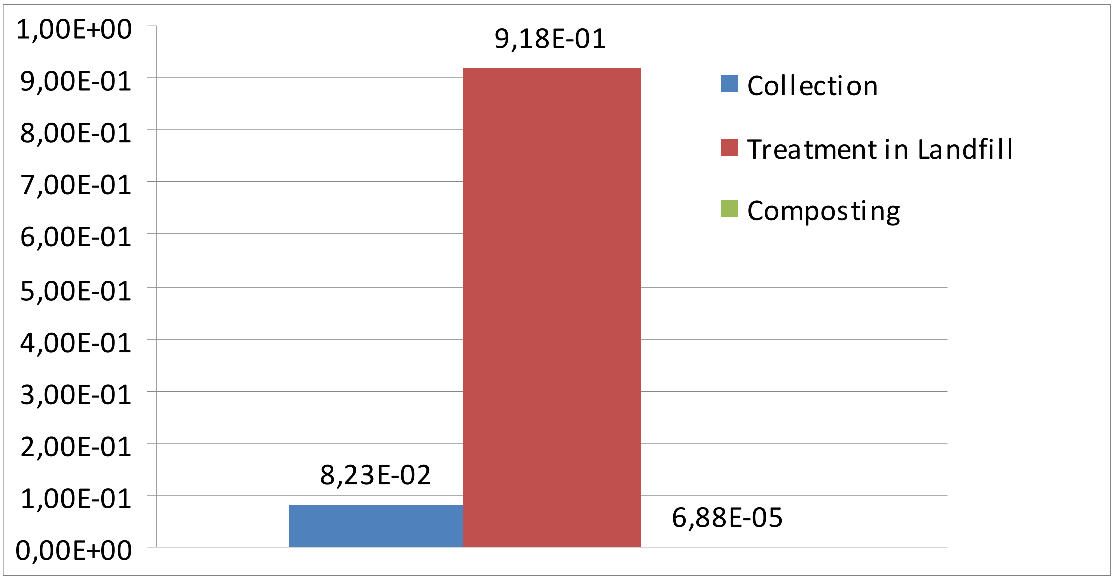


Figure 35. Share of emergy investment in Scenario 2

As mentioned above, scavenging and composting are the source of emergy recovery. Table 37 to 39 describes the emergy recovery from each scenario. The matter/ money recovery is calculated by dividing the product for the amount of waste treated. Emergy recovery is calculated by multiplying matter or money recovery for the correspondent transformity. The emergy recovery from landfilling is the conversion of the income of the scavengers to the solar emergy by multiplying it to national emergy per unit dollar (2.06E+13 seJ/$). Compost is assumed to have the same content as natural fertilizer with 1.32% natrium (N), 0.88% phosphorus (P), 1.15% potassium (K) and the rest is the remaining part (Marchettini, 2006). The calculation of emergy in composting uses the transformity of the fertilizer component (N, P, K) and the land cycle from Odum (1996).

Table 37. Emergy recovery of Scenario 0

	Product	Unit	Matter/money recovery [unit/gMSW]	Transformity [seJ/unit]	Emergy recovery [seJ/gMSW]
Composting	**4.72E+09**	g	**3.30E-01**		**3.97E+08**
N(1,32%)	6.24E+07	g	4.36E-03	4.62E+09	2.01E+07
P(0,88%)	4.16E+07	g	2.90E-03	1.78E+10	5.17E+07
K(1,15%)	5.43E+07	g	3.79E-03	1.74E+09	6.60E+06
Remaining part	4.57E+09	g	3.19E-01	1.00E+09	3.19E+08
Landfiling	**4.35E+04**	$	**2.43E-07**	**2.06E+13**	**5.00E+06**
Total					**4.02E+08**

Table 38. Emergy recovery of Scenario 1

	Product	Unit	Matter/money recovery [unit/gMSW]	Transformity [seJ/unit]	Emergy recovery [seJ/gMSW]
Composting	**2.78E+10**	**g**	**3.30E-01**		**3.97E+08**
N(1,32%)	3.67E+08	g	4.36E-03	4.62E+09	2.01E+07
P(0,88%)	2.44E+08	g	2.90E-03	1.78E+10	5.17E+07
K(1,15%)	3.19E+08	g	3.79E-03	1.74E+09	6.60E+06
Remaining part	2.68E+10	g	3.19E-01	1.00E+09	3.19E+08
Landfiling	**4.35E+04**	**$**	**2.00E-07**	**2.06E+13**	**4.12E+06**
Total					**4.01E+08**

Table 39. Emergy recovery of Scenario 2

	Product	Unit	Matter/money recovery [unit/gMSW]	Transformity [seJ/unit]	Emergy recovery [seJ/gMSW]
Composting	**2.78E+10**	**g**	**3.30E-01**		**3.97E+08**
N(1,32%)	3.67E+08	g	4.36E-03	4.62E+09	2.01E+07
P(0,88%)	2.44E+08	g	2.90E-03	1.78E+10	5.17E+07
K(1,15%)	3.19E+08	g	3.79E-03	1.74E+09	6.60E+06
Remaining part	2.68E+10	g	3.19E-01	1.00E+09	3.19E+08
Landfiling	**8.70E+06**	**$**	**4.00E-05**	**2.06E+13**	**8.24E+08**
Total					**1.22E+09**

The calculation of emergy recovery presented in Table 37 to 39 clearly shows that composting and scavenging can extract the economic value from waste by generating the flows of money. The highest emergy recovery is produced under Scenario 2 with the value of 1.22E+09 seJ/gMSW. Scenario 0 and Scenario 1 can generate the relative same amount of emergy saving (4.02E+8 seJ/gMSW) although the emergy input in Scenario 0 is higher than Scenario 1. The same scavenging rate and the higher composting rate than Scenario 1 and the higher LoS compared to Scenario 0 cause this, since matter recovery depends not only on the product but also the waste treated.

Scenario 1 and 2 has the same amount of emergy recovery from composting because both scenarios have the same composting rate of 50%. Thus, the value is higher compared to that of Scenario 0 which covers only 10.33% composting rate. The emergy recovery from landfilling of Scenario 2 is the highest compared to other scenarios. The higher scavenging rate involving 200 scavengers is the reason for this.

The analysis of emergy indices is conducted to measure whether one scenario which satisfies the criteria of the above values is really better than any other scenarios. Using these indicators, the evaluation is more comprehensive since it covers not only an assessment from one view of point but also other view of points such as its efficiency and sustainability.

Based on values in Tables 34 to 39, the emergy indices of each scenario is calculated and presented in Table 40

Table 40. Emergy evaluation of Scenarios

	S0	S1	S2
Total solar emergy [seJ/y]	**3.03E+23**	3.78E+23	3.97E+23
Emegy Investment [seJ/g MSW]	1.84E+12	**1.74+12**	1.82E+12
Emergy recovery [seJ/g MSW]	4.02E+08	4.01E+08	**1.22E+09**
EYR	2.18E-04	2.31E-04	**6.69E-04**
Net Emergy [seJ/g MSW]	-1.84E+12	**-1.74E+12**	-1.82+12
ELR	4.95E+05	5.36E+05	**1.34E+05**
ESI	4.41E-10	4.31E-10	**5.00E-09**

The EYRs shows that Scenario 2 has the highest EYR compared to Scenario 0 and Scenario 1. It indicates that Scenario 2 is the most efficient alternative in recovering emergy from MSW, although Scenario 2 needs the highest total solar emergy. The Net Emergy shows that all scenarios have the negative value. It means that none of the scenario is capable of saving the greatest quantity of emergy per unit weight of MSW treated. The emergy investment is higher than the emergy recovery. It is because all scenarios have less output than much input. However, Scenario 1 supply relatively higher benefits compared to other scenarios because it has highest Net Emergy. Scenario 2 has the lowest ELR reflecting that the pressure on the environment caused by the activities under Scenario 2 is lower than other two secnarios. A waste treatment method is considered suitable if it is characterized by high EYR and the low ELR. Scenario 2 meets these requirements causing the highest ESI. It implies that Scenario 2 is more sustainable compared to Scenario 0 and Scenario 1. The highlighted value in Table 40 is the value that meets the criteria of each parameter.

7. Conclusion and Recommendations

The local government of Yogyakarta in Indonesia will construct a new SWDS not so far from the old landfill. The new SWDS have to be operated as a safe landfill to obey the Waste Law 18/2008 Article 22 and Article 44. Due to the inferior waste management conditions in Yogyakarta, the new SWDS will be a controlled landfill. The existing of the scavengers is also another factor for the option of a controlled landfill. The evaluation of the old landfill showed that scavengers has role in reducing the waste. The involvement of scavengers in the old landfill contributed 7.5% reduction on plastics and 12.8% reduction on paper. Furthermore, they were responsible also for reduction on metal and glass although the percentage was very little (below 0.01%). Using IPCC Tier 2 Method, the methane emission from the old landfill has been calculated. The result demonstrated that the involvement of 45 scavengers in Bendo landfill contributed 0.7% emission reduction. The value was not significant compared to the amount of the degradable waste (paper) sorted since there was no major reduction on organic waste. A considerable organic waste reduction, for example through composting, can effect the methane emission substantially. The increasing number of scavengers was a minor factor compared to the increasing amount of organic waste prevented from disposal in landfill.

The results of the evaluation have been used to determine the appropriate scenario for the new controlled landfill. The involvement of scavengers in the new landfill is considered, since the result indicated that scavenging has contributed waste reduction and LFG emission. Three scenarios of final waste treatment have been evaluated in this PhD study. The evaluation included two environmental parameters; the global warming potential (GWP) and the emergy indices covering some indicators. The estimation of GWP in form of emission of equivalent carbon dioxide shows that the involvement of scavenger in reducing waste in SWDS has less significant contribution in reducing GWP from SWDS. Organic waste reduction through composting affects GWP potential reduction more intensely. Higher percentage of composting in Scenario 1 and 2 contributed the lower GWP from SWDS compared to Scenario 0. Scenario 2 which covered the landfill with open flare system reduced the most GWP.

The application of indicators in emergy analysis such as emergy indices is significant in evaluating the final waste treatment because it enables the assessment of sustainability and efficiency of each scenario. It allows the analysis of environmental cost and benefits of a certain final waste treatment. Therefore, the emergy indices of three scenarios are compared. The results of the analysis demonstrated that Scenario 0 contributes the lowest solar emergy and Scenario 2 requires the highest solar emergy. Meanwhile, Scenario 1 had the lowest value of emergy investment. The construction of LFG collection system demands significant additional cost causing the higher emergy input for Scenario 2. Yet, the increasing amount of waste collected caused the decrease of emergy investment. Therefore, Scenario 1 and 2 had lower emergy investment compared to Scenario 0. In all scenarios, landfilling process needed the highest emergy investment which was mainly contributed by emergy input from fuel and plant construction. The involvement of scavenger in landfill contributed a positive emergy recovery since it generates income from landfill. Therefore, the new landfill should not eliminate scavenging totally. The evaluation of the environmental parameters is presented in Table 41.

Table 41. The evaluation of the scenarios

	S0	S1	S2	Criteria
Global warming potential	-	-	√	lower
Total solar emergy	√	-	-	lower
Emegy Investment	-	√	-	lower
Emergy recovery	-	-	√	higher
EYR	-	-	√	higher
Net Emergy	-	√		higher
ELR	-	-	√	lower
ESI	-	-	√	higher

The evaluation of the scenarios for final waste treatment in Yogyakarta can be used as a reference to determine the appropriate alternative. The cost for the improper final waste treatment and the benefit for better implementation of final waste treatment have been provided in this study. According to the value of the environmental parameters analyzed in the study, Scenario 2 show the best result since it has more environmental parameters which fulfill the criteria.

Sustainable is characterized by positive yield, high renewability and low load on the environment. A process is not suitable if the yield is low because it requires continuing flow of invested emergy. Meanwhile, if a process depends completely on non renewable resource, it is also not sustainable. Finally, if a process situates tremendous load on the environment, it may lead to damages which can threaten long term sustainability. The GWP and emergy evalution of the scenario shows that actually none of the scenarios fulfils the requirements of sustainability well. Therefore, the local government should seek the solutions to increase the emergy recovery, to decrease the emergy investment, and to minimize the adverse environmental effect. Some ways can be implemented in the future for better final waste treatment method in Yogyakarta City such as:

1. The enhancement of awareness of all related stakeholders in MSW to improve the implementation of 3R which can decrease the waste disposal in landfill and increase the material recovery.
2. Introducing an appropriate financial scheme to improve the MSWM including action to sustain future controlled landfill. The improvement of the collection fee system based on the Pay as You Throw (PAYT) principles can be applied to increase the income from the waste sector. Furthermore, the local government should involve the private sector in managing the LFG from the old landfills and in developing them as Clean Development Mechanism (CDM) projects. This is important since the financial aspect is the main influence on the current conditions of MSWM in these cities.
3. Utilization of the methane emission for electrical generation can increase the emergy recovery. The construction of the LFG collection system for WtE purposes requires high investment, but it brings benefits for the community and the environment. For that reason, the improvement of data and information on waste generation and waste characteristic as well as waste management should be conducted to calculate the profit for such plant more precisely.
3. Study has shown that the informal sector in waste management contribute waste reduction. Therefore, scavenging can be accommodated. Nonetheless, improvement of the condition by providing proper equipments for safety and health reason (mask, boots, gloves, etc) is required. The management of time, the restriction of the area for sorting, ban for illegal shelter, selling activities in landfill site are compromises for the situation.
4. Innovations of locally adjusted technology can support the sustainability since it can minimize the dependent to the external resource. The use separable garbage bin in collection system and mechanical shredder with moderate capacity are few examples that can be implemented.

8. List of Publications

Journals

1. Meidiana, C. and Gamse, T., (2010), *Development of Waste Management Practices in Indonesia*. European Journal of Scientific Research. 40, (2), 199 – 210.

2. Meidiana, C. and Gamse, T., (2011). *The New Waste Law: Challenging Opportunity for Future Landfill Operation in Indonesia*. Waste Management and Research, 29 (1), 20 – 29.

Proceedings

1. Meidiana, C. and Gamse, T., (2010), Solid *Waste Management in Indonesia: Lesson learnt from Austria*. Proceedings of the International Conference on Sustainable Architecture and Urban Design, Penang Malaysia, pp. 351 – 362.

2. Meidiana, C. and Gamse, T., (2010), *The New Waste Law: Challenging Opportunity for Future Landfill Operation in Indonesia*. Proceedings of the 1st International Conference on Final Sinks, Vienna, Austria, pp. 69 – 74.

3. Meidiana, C. and Gamse, T., (2011), *Scavenging in Landfill: Contributions to Sustainable Landfilling in Developing Countries?* Proceedings of the International Conference of Solid Waste, Moving Towards Sustainable Resource Management, Hongkong, pp. 195 – 198.

Presentations

1. *Potentials and Challenges of Landfill Gas Emission Prevention in Indonesia*. Poster presentation at The 5th Mini symposium of Chemical Engineering, Vienna, Austria, 24 – 25 June 2009.

2. *Perspective for Environmentally Sound Landfill in Economically Developing Cities in Indonesia*. Oral presentation at The 6th Mini symposium of Chemical Engineering, Tulln, Austria, 24 – 25 June 2010.

3. *The Role of Policies in GHG Emission Reduction from Waste Sector. Case study of Developed and Developing country*. Keynote at The South-East European Conference on Waste Management and Recycling, Sofia, Bulgaria, 28 – 30 March 2012

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Calculation of Methane Emission for Scenario 0

Year	Compostable	Paper	Textile	Nappies	Wood	Total Emission
2013	0	0	0	0	0	0
2014	1272,87	58,91	14,54	15,66	3,10	1365,08
2015	2256,26	114,78	28,33	30,52	6,15	2436,04
2016	3030,56	167,85	41,42	44,62	9,16	3293,61
2017	3652,08	218,30	53,88	58,04	12,12	3994,42
2018	4160,65	266,34	65,73	70,81	15,04	4578,57
2019	4584,69	312,14	77,03	82,99	17,92	5074,77
2020	4944,71	355,87	87,83	94,61	20,77	5503,79
2021	5255,72	397,69	98,15	105,73	23,58	5880,87
2022	5528,81	437,75	108,03	116,38	26,36	6217,33
2023	5772,31	476,17	117,52	126,60	29,10	6521,70
2024	5992,54	513,09	126,63	136,41	31,82	6800,50
2025	6194,39	548,63	135,40	145,86	34,52	7058,80
2026	6381,66	582,90	143,86	154,97	37,19	7300,57
2027	6557,34	616,00	152,03	163,77	39,84	7528,97
2028	6723,84	648,03	159,93	172,29	42,47	7746,55
2029	6883,08	679,08	167,59	180,54	45,06	7955,35
2030	5393,15	633,17	156,26	183,16	43,51	6409,26
2031	4272,59	590,37	145,70	185,93	42,02	5236,61
2032	3418,68	550,46	135,85	188,71	40,57	4334,28
2033	2759,57	513,25	126,67	191,50	39,18	3630,17
2034	2244,60	478,55	118,11	178,56	37,83	3057,65
2035	1837,69	446,20	110,12	166,49	36,53	2597,03
2036	1512,86	416,04	102,68	155,23	35,27	2222,08
2037	1251,19	387,92	95,74	144,74	34,06	1913,64
2038	1038,72	361,69	89,26	134,95	32,89	1657,52
2039	865,03	337,24	83,23	125,83	31,76	1443,10
2040	722,23	314,45	77,60	117,33	30,66	1262,27
2041	604,24	293,19	72,36	109,39	29,61	1108,79
2042	506,38	273,37	67,47	102,00	28,59	977,81
2043	424,94	254,89	62,91	95,10	27,61	865,45
2044	356,98	237,66	58,65	88,68	26,66	768,63
2045	300,15	221,59	54,69	82,68	25,74	684,85
2046	252,54	206,61	50,99	77,09	24,86	612,10
2047	212,60	192,65	47,54	71,88	24,00	548,68
2048	179,06	179,62	44,33	67,02	23,18	493,21
2049	150,86	167,48	41,33	62,49	22,38	444,55
2050	127,14	156,16	38,54	58,27	21,61	401,72
2051	107,17	145,60	35,93	54,33	20,87	363,90
2052	90,36	135,76	33,51	50,66	20,15	330,43
2053	76,19	126,58	31,24	47,23	19,46	300,70
2054	64,25	118,03	29,13	44,04	18,79	274,23
2055	54,19	110,05	27,16	41,06	18,14	250,60
2056	45,71	102,61	25,32	38,29	17,52	229,44
2057	38,55	95,67	23,61	35,70	16,91	210,45
2058	32,52	89,21	22,02	33,28	16,33	193,36
2059	27,43	83,18	20,53	31,03	15,77	177,94
2060	23,14	77,55	19,14	28,94	15,23	164,00

Calculation of Methane Emission for Scenario 1

Year	Compostable	Paper	Textile	Nappies	Wood	Total emission
2013	0	0	0	0	0	0
2014	861,84	73,56	17,65	19,02	5,27	977,34
2015	1527,68	143,33	34,40	37,06	10,44	1752,90
2016	2051,95	209,59	50,30	54,19	15,51	2381,53
2017	2472,77	272,59	65,42	70,48	20,51	2901,76
2018	2817,12	332,57	79,82	85,98	25,41	3340,90
2019	3104,23	389,76	93,54	100,77	30,24	3718,55
2020	3347,99	444,37	106,65	114,89	35,00	4048,90
2021	3558,57	496,59	119,18	128,39	39,69	4342,42
2022	3743,48	546,61	131,18	141,32	44,31	4606,89
2023	3908,35	594,59	142,70	153,73	48,86	4848,22
2024	4057,47	640,69	153,76	165,65	53,36	5070,93
2025	4194,14	685,07	164,41	177,12	57,80	5278,54
2026	4320,93	727,85	174,68	188,18	62,19	5473,84
2027	4439,88	769,18	184,60	198,87	66,54	5659,07
2028	4552,61	809,18	194,20	209,21	70,83	5836,03
2029	4660,43	847,95	203,51	219,23	75,09	6006,21
2030	3651,63	790,63	189,75	204,41	72,51	4908,92
2031	2892,91	737,18	176,92	190,59	70,01	4067,62
2032	2314,74	687,35	164,96	177,71	67,61	3412,37
2033	1868,47	640,88	153,81	165,70	65,28	2894,14
2034	1519,79	597,56	143,41	154,50	63,04	2478,30
2035	1244,28	557,17	133,72	144,05	60,87	2140,08
2036	1024,34	519,50	124,68	134,31	58,77	1861,61
2037	847,16	484,38	116,25	125,23	56,75	1629,79
2038	703,30	451,64	108,39	116,77	54,80	1434,91
2039	585,70	421,11	101,07	108,87	52,92	1269,67
2040	489,01	392,64	94,23	101,52	51,10	1128,50
2041	409,12	366,10	87,86	94,65	49,34	1007,08
2042	342,86	341,35	81,92	88,25	47,64	902,04
2043	287,72	318,28	76,39	82,29	46,00	810,67
2044	241,71	296,76	71,22	76,73	44,42	730,84
2045	203,23	276,70	66,41	71,54	42,89	660,77
2046	170,99	258,00	61,92	66,70	41,42	599,03
2047	143,95	240,56	57,73	62,19	39,99	544,43
2048	121,24	224,29	53,83	57,99	38,62	495,97
2049	102,15	209,13	50,19	54,07	37,29	452,83
2050	86,08	194,99	46,80	50,41	36,01	414,30
2051	72,56	181,81	43,63	47,01	34,77	379,79
2052	61,18	169,52	40,69	43,83	33,57	348,79
2053	51,59	158,06	37,93	40,87	32,42	320,87
2054	43,50	147,38	35,37	38,10	31,31	295,66
2055	36,69	137,42	32,98	35,53	30,23	272,84
2056	30,95	128,13	30,75	33,13	29,19	252,14
2057	26,10	119,47	28,67	30,89	28,19	233,31
2058	22,02	111,39	26,73	28,80	27,22	216,16
2059	18,57	103,86	24,93	26,85	26,28	200,49
2060	15,67	96,84	23,24	25,04	25,38	186,16

Calculation of Methane Emission for Scenario 2

Year	Compostable	Paper	Textile	Nappies	Wood	Total emission
2013	0	0	0	0	0	0
2014	861,84	43,64	17,65	19,02	5,27	947,42
2015	1527,68	85,03	34,40	37,06	10,44	1694,61
2016	2051,95	124,34	50,30	54,19	15,51	2296,29
2017	2472,77	161,72	65,42	70,48	20,51	2790,90
2018	2817,12	197,31	79,82	85,98	25,41	3205,64
2019	3104,23	231,24	93,54	100,77	30,24	3560,02
2020	3347,99	263,64	106,65	114,89	35,00	3868,17
2021	3558,57	294,62	119,18	128,39	39,69	4140,45
2022	3743,48	324,29	131,18	141,32	44,31	4384,58
2023	3908,35	352,76	142,70	153,73	48,86	4606,39
2024	4057,47	380,11	153,76	165,65	53,36	4810,35
2025	4194,14	406,44	164,41	177,12	57,80	4999,91
2026	4320,93	431,83	174,68	188,18	62,19	5177,81
2027	4439,88	456,35	184,60	198,87	66,54	5346,23
2028	4552,61	480,07	194,20	209,21	70,83	5506,93
2029	4660,43	503,08	203,51	219,23	75,09	5661,34
2030	3651,63	469,07	189,75	204,41	72,51	4587,36
2031	2892,91	437,36	176,92	190,59	70,01	3767,80
2032	2314,74	407,80	164,96	177,71	67,61	3132,81
2033	1868,47	380,23	153,81	165,70	65,28	2633,48
2034	1519,79	354,53	143,41	154,50	63,04	2235,26
2035	1244,28	330,56	133,72	144,05	60,87	1913,47
2036	1024,34	308,21	124,68	134,31	58,77	1650,32
2037	847,16	287,38	116,25	125,23	56,75	1432,78
2038	703,30	267,95	108,39	116,77	54,80	1251,22
2039	585,70	249,84	101,07	108,87	52,92	1098,40
2040	489,01	232,95	94,23	101,52	51,10	968,81
2041	409,12	217,20	87,86	94,65	49,34	858,18
2042	342,86	202,52	81,92	88,25	47,64	763,20
2043	287,72	188,83	76,39	82,29	46,00	681,23
2044	241,71	176,06	71,22	76,73	44,42	610,14
2045	203,23	164,16	66,41	71,54	42,89	548,23
2046	170,99	153,07	61,92	66,70	41,42	494,10
2047	143,95	142,72	57,73	62,19	39,99	446,59
2048	121,24	133,07	53,83	57,99	38,62	404,75
2049	102,15	124,08	50,19	54,07	37,29	367,77
2050	86,08	115,69	46,80	50,41	36,01	334,99
2051	72,56	107,87	43,63	47,01	34,77	305,84
2052	61,18	100,58	40,69	43,83	33,57	279,84
2053	51,59	93,78	37,93	40,87	32,42	256,58
2054	43,50	87,44	35,37	38,10	31,31	235,72
2055	36,69	81,53	32,98	35,53	30,23	216,95
2056	30,95	76,02	30,75	33,13	29,19	200,03
2057	26,10	70,88	28,67	30,89	28,19	184,72
2058	22,02	66,09	26,73	28,80	27,22	170,85
2059	18,57	61,62	24,93	26,85	26,28	158,25
2060	15,67	57,45	23,24	25,04	25,38	146,78

Appendix A1.

Calculation of Exergy for Collection

	demand	existing	Unit
1. Labor used in the TP collection			
People employed in the collection	293	193	workers
Days of work per year	301	301	days/yr
Energy of the metabolism	2500	2500	cal/day
Conversion factor 4.19E+03 J/kcal	4190	4190	J/cal
Total energy per year J/year	9.24E+11	6.09E+11	J/year
Payment	**2.99E+05**	**1.97E+05**	$/yr
2. Labor used in the DtD collection			
People employed in the collection	773	727	workers
Days of work per year	301	301	days/yr
Energy of the metabolism	2500	2500	cal/day
Conversion factor 4.19E+03 [J/kcal]	4190	4190	J/cal
Total energy per year [J/year]	2.44E+12	2.29E+12	J/year
Total emergy labor DtD & TP	**3.36E+12**	**2.90E+12**	J/year
Payment	7.89E+05	7.42E+05	$/yr
Total labor cost	**1.09E+06**	**9.39E+05**	$/yr
Maintenance 10% capital	1.50E+04	1.10E+04	$/yr
Total Management cost	**1.10E+06**	**9.50E+05**	$/yr
3.Fuel for collection			
Kilometers per fuel liter	3.85	3.85	km/l
Distance covered per month	2.80E+04	2.43E+04	km/month
Months of collection per year	1.20E+01	1.20E+01	months/year
Liters spent in the collection per year	8.73E+04	7.58E+04	l/year
Total of wastes collected per year [t/year]	1.49E+05	1.44E+05	t/year
Total collected per fuel liter	1.70E+00	1.90E+00	t/L
Fuel energy content	3.60E+07	3.60E+07	J/L
Energy for collection per year	3.14E+12	2.73E+12	J/yr

Calculation of Exergy for Landfill

	70% LoS	85% LoS	Unit
1. Labor used in the landfill			
People employed in the landfill	2	2	workers
Days of work per year	301	301	days/yr
Energy of the metabolism	2500	2500	cal/day
Conversion factor 4.19E+03 J/kcal	4190	4190	J/cal
Total energy per year	6,31E+09	6,31E+09	J/year
Payment Rp808000/mnth	**2041,26**	**2041,26**	**$/yr**
2. Scavenger			
Scavenger in the landfill	45	200	workers
Days of work per year	301	301	days/yr
Energy of the metabolism	2500	2500	cal/day
Conversion factor 4.19E+03 J/cal	4190	4190	J/cal
Total energy per year	1.42E+11	6.31E+11	J/year
3. Electricity			
Electricity Power	3500	3500	Watt
operation hour	8	8	hour
days of work per year	301	301	days/yr
Assumption maximum consumption	8.43E+06	8.43E+06	Wh/yr
Conversion factor	3600	3600	J
Total energy per year	3.04E+10	3.041E+10	J/yr
Price for abonement (Rp 57200)	6.02	6.02	$
Price per kWh (Rp 650/kWh)	0.07	0.07	$/kWh
Purchased	579.13	579.13	$/yr
4. Fuel			
Kilometers per fuel liter	3.85	3.85	km/l
Area	1.50E+04	1.50E+04	m^2
No of vehicles	3	9	
Speed	20	20	km/h
Hours per day	8	8	hour
days of work per year	301	301	
Total distance per year	1.45E+05	4.34E+05	km/yr
Liters spent per year	3.76E+04	1.13E+05	l/yr
Fuel energy content	3.60E+07	3.60E+07	J/L
Energy for operation per year	1,3523E+12	4,06E+12	J/yr
Price fuel	1.1	1.1	$/l
Total fuel price	4.13E+04	1.24E+05	$/y

Calculation of Exergy for Composting

83 composting centre, total 614 community unit (CU) (1 composting centre 6-7 CU)

each composting centre 1 handcart

production per centre 100 kg/day

Compost production : 0,332 kg compost/1 kg compostable waste

	LoS 10.33%	LoS 50%	Unit	Total	Unit
1. Labor used in the composting centre					
People employed in the composting	581	747	workers		
Days of work per year	301	301	days/yr		
Energy of the metabolism	2500	2500	cal/day		
Conversion factor 4.19E+03 J/kcal	4190	4190	J/cal		
Total energy per year 1.35E+12 J/year	1.83E+12	2,36E+12	J/year		
2. Electricity					
Electricity Power	2200	2200	Watt		
operation hour	8	8	hour		
days of work per year	301	301	days/yr		
Assumption max. Consumption	5.30E+06	5,30E+06	Wh/yr		
Conversion factor	3600	3600	J		
Total energy per year	1.91E+10	1,91E+10	J/yr		
3. Construction					
Area	300	300	m2		
office building (OB)	45	45	m2		
composting area (CA)	200	200	m2		
Price of area	105.26	105,26	$/m2	31578,95	$
Price of Building	263.16	263,16	$/m2	11842,11	$
Price of Composting Area	157.89	157,89	$/m2	31578,95	$
Construction cost				75000,00	$
4. maintenance (15% construction cost)	11,250	11,250	$		
5. Management cost (incld. Maintenc)	**6.06E+05**	**7.76E+05**	$		
a. Labor					
People employed in the composting	581	747	workers		
Days of work per year	12	12	months/yr		
Payment (Rp 808000/bln) 2010	85.05	85.05	$/mnth		
Total	5.93E+05	7.63E+05	$/yr		
Total emergy	7.12E+17	9.15E+17	sej/yr		
b. Electricity					
Assumption maximum consumption	5.30E+06	5.30E+06	Wh/yr		
Price for abonement (Rp 57200)	6.02	6.02	$		
Price per kWh (Rp 650/kWh)	0.068	0.068	$/kWh		
Total	366.26	366.26	$/yr		

c. Fuel price				
Fuel for shredder (diesel 22 PK, 2m³/hr)	1	1	l/h	
operation hour	3	5	hour/day	
Days of work per year	301	301	days/yr	
Price diesel (Februari 2011) Rp 8650	1.1	1.1	$/l	
Total	993,3	1655.5	$/yr	
Price of shredder (Rp 800.000)	84.1	84.21	$	
d. Fuel energy				
Fuel for shredder (diesel 22 PK, 2m³/hr)	1	1	l/h	
operation hour	3	5	hour/day	
Days of work per year	301	301	days/yr	
Fuel energy content	3.60E+07	3.60E+07	J/l	
Energy total	3.25E+10	5.42E+10	J/yr	

6. Air	10.33%	50%		
Optimal composting	33	33	%	of pore space in compostable mass
Air demand	5	5	%	of pore space
mass of waste	1.19E+10	5.75E+10	g/yr	
Amount = mass of waste * [%] pore space*[%] air demand				
Amount	1.96E+08	9.48E+08	g/yr	

Calculation of Exergy for Equipment

No	Equipment	Demand (85% LoS)	Existing (70% LoS)	Heavy (kg/unit)	Amount [kg/yr]	[g/yr]
	Collection					
1	Dump Truck	43	36	2,000	5,733.33	
2	Arm roll Truck	12	11	2,000	1,600.00	
3	Street Container	66	40	2,000	8,800.00	
4	Depo	14	12			
5	handcart	773	193	24	3,710.40	
6	Pick up truck	8	6	2,000	1,066,67	
7	Backhoe Loader	1	1	8,400	560.00	
					21,470.40	**21,470,400**
	Landfill					
1	compactors	2		20,000	2,666,67	
2	wheel loader	3		16,500	3,300,00	
3	Dump Truck	4		2000	533.33	
					6,500	**6,500,000**

Amount = number of vehicles * weight/vehicle (estimated) /life time (estimated) *specific energy

Specific energy [MJ/kg]	heavy vehicles	32
	light vehicles	286
	handcart	56

	demand	existing	Unit
Collection			
Dumptruck	1.84E+11	1.54E+11	J/yr
Armrolltruck	5.12E+10	4.69E+10	J/yr
Street container	2.82E+11	1.71E+11	J/yr
Pickup truck	3.05E+11	2.29E+11	J/yr
Handcart	2.08E+11	3.33E+11	J/yr
Backhoe loader	1.79E+10	1.79E+10	J/yr
Total	**1.05E+12**		
Landfill			
Compactors	8.53+10	4.27E+10	J/yr
wheel loader	1.06E+11	3.52E+10	J/yr
Dumptruck	1.71E+10	4.27E+09	J/yr
	2.08E+11	**8.21E+10**	J/yr

Questionnaires for Institution

Name of Institution :
Address :
Contact Person :
Phone/Facsimile :

A. Institutional Data

1. Describe department/ministries or authorities which is responsible for waste management in :
   (a) national level ____
   (b) regional level ____
   (c) local level ____

2. How much budget is allocated yearly for municipal solid waste management (MSWM)?
   (a) Total _________________ (b) Operational _________________
   (c) Maintenance _________________ (d) Others _________________

3. Source of finance for the institution to manage (MSW). Mentioned the source and the institution)
   (a) _____________________________
   (b) _____________________________
   (c) _____________________________

4. How much does your institution need for (MSWM)? (Collection, transport, disposal, Administration) _________/ year
5. How much deficit/surplus per year ? (nominal _________ and/or percentage ___________
6. How is the collection fee system paid? Choose one or more
   (a) individual direct payment
   (b) payment attached to other bill (water or electricity)
   (c) collective payment through community unit
   (d) other (mention)
7. Does your institution accept aid or loan from international institution for MSWM? (International Financial Institutions, Non-Government Organizations, etc.)
   Yes ☐ No ☐
   If yes, mentioned
8. How many staff are working in your department ?
   Full time : ______ people . Unit/Division:
   Part time : ______. people Unit/Division:
   Other
   Are they adequate and meet the qualifications? Yes ☐ No ☐
   Do they meet the qualifications? Yes ☐ No ☐

B. Data on Waste (Quantitative & Qualitative)

1. The amount of waste collected and disposed of in landfill (Time series data)
   1000 ton/th
2. The average tonnage per capita per year (kg /capita/day)
3. Waste composition (in weight, volume or percentage)
   compostable (food waste, garden waste, wood etc.) _______________
   paper _______ plastic __________ glass__________ metal
   others (i.e. ceramics, textile, leather, rubber, ash, electronic waste atau bulky waste________

4. The amout of waste per day (weight or volume) produced by :

Source:

Household ______ Commercial (retail, shops, hotels, etc.) _____ Market____________

Institution (hospital, offices, schools) ________ industries ________

Disposed of or treated

Reused __________ Recycled _________ Open burning _________ Composted _________

Incinerated ______________ delivered to landfill ______________

Others : ____

5. Number of transfer depo and each capacity

C. Waste Processing

1. Does your department have a 3R program for community ? (If Yes, mentioned)
2. Is there any partnership programs in 3R program? (If Yes, mentioned)
3. Describe shortly the implementation of 3R program
3. Does your department operate

(a) incinerator for municipal and medical waste? Yes ☐ No ☐

If yes, mention the operation load hrs/day/week ____________ weeks/year

Power generated (if any)______________ kWh.

Cost:

Total __________ operational ___________

Fuel (Yes / No): super _____ gas _____ kerosene

Ash disposal ___________

Hindrances

(b)Composting plant Yes ☐ No ☐

If yes, describe : composting rate __________ ton/month _____________ ton/year

Market :

Investment ____________________operational cost_________________________

Hindrances ____

(c) Is there any community based composting plant?

Yes ☐ No ☐

If yes, describe the capacity, production, stakeholders

(d) Does your department support community based composting centres

Yes ☐ No ☐

If yes, mention the location ________ capacity ___________

Production ___________ no. of Household involved ________________

Partnership ___________

D. Collection, Transfer and Disposal)

1. Does your department has waste collection system? Yes ☐ No ☐
2. What is the percentage of people provided by waste collection system?
   Regular base : ________ times/day or ________times/week or periodic __________
3. What time is the waste usually collected (hour) ________ - _________
3. Is waste collection conducted by regular staff or contractor?

4. Mention the number of the following equipment:
   (a) manual equipment (non-vehicle i.e. rickshaw) ______ operated: ___________ Non operated : ___________
   Average operasional rate: (operated divided by total no. of manual equipment)______%
   Reasons for non-operated equipments : _________
   ____
   (b) Vehicles (trucks, pick up)
   Dump truck ________ compactor truck ____ ____pick up ________Others___________
   Operated: _____________ Non operated : ___________
   Average operasional rate: (operated divided by total no. of manual equipment)______%
   Reasons for non-operated equipments : _________

5. If operational level is not optimum, how many equipment is needed more?
   (a) For waste collection _______________________________________
   (b) For waste transfer _____________________________________
   (b) For landfill operation _______________________________________
6. What is the percentage of waste collection?
7. Is there street sweeping? Yes ☐ No ☐
   If yes:
   (a) Conducted by deprtament or private?
   (b) Is it : ☐manual, ☐mechanical, or ☐ both
   (c) At what time usually
8 Are there any transfer depo? Yes ☐ No ☐.
   If yes, mention the volume ________ frequency _________ number _______
   No. of worker/depo _________ tools/method ____________
   Waste separation (if any), hindrances _____________

9. Do you operate or manage
   open dumps Yes ☐ No ☐
   controlled dumps Yes ☐ No ☐
   sanitary landfills Yes ☐ No ☐
   If yes explain: location __________ distance from city ____________ Capacity ____________ Facility ______________ waste separation _____________
   Incidents (if any) : i.e. fires, pollution, odor, etc
10. The landfill is managed by:
   (a) Local government Yes ☐ No ☐
   (b) Private Yes ☐ No ☐
   (c) Both Yes ☐ No ☐
   (c) Equipped by adequate facility? Yes ☐ No ☐
   (d) Is there any equipment rent for certain time? Yes ☐ No ☐
   (e) What kid of facilities operated by landfill operator? (i.e. heavy vehicles, WWTP, incinerator).
   (f) Name of landfill :
   (g) Opening year :
   (h) Closing year :

   If the landfill close to closing year, does the local government has the plan for the new landfill?

   Yes ☐ Location : Open year : _______________

   No ☐ Reason : ____

11. Is there any policy related to scavenging activities in landfill?
12. Your comments about waste pickers involvement in waste separation in waste management.

E. Issues on General policy

1. Doe your institution participate in program of community awareness or education on waste?

   Yes ☐ No ☐
   If yes, mention the method ____
   If no, why? ____
   Doe your institution involve in innovation project of municipal waste management?

(a) Is there any community participation in waste separation, collection and disposal in form of informal organisations?. Yes ☐ No ☐
(b) Is there any public-private partnerships program lead to privatisation in MSWM?
    Yes ☐ No ☐
(c) Is there any program for restructurisation, training progrm for staff or control program for efficiencies? Yes ☐ No ☐
    If yes, explain ____

Questionnaires for Waste Picker

No. of respondent: ____________________________

Location: ____________________________________

Date: ____________________________

1. Name? ____
2. Age? __________________________
3. Education?
4. Marital status? (Please circle.)

   Marriage/divorced/widow/single
5. address of origin? _________________,__________________

   Current address? _________________,__________________

   Do you live inside the landfill site?
6. How many people live in your house? _______________
7. How many are under 16 years old? _______________
8. How many people in your house have their own income? ______________

   a. Is there under 16 years old? Yes/No
   b. If Yes : How many? ___________
9. How long have you been working here? ……..year(s) and/or ……. Month(s)
10. Are you registered as scavenger in this landfill? If Yes, is there any organization which accommodate it?
11. Do you have to pay for membership?
12. What kind waste do you sort?

    a. plastic b. glass c. metal d. paper e. others (mention)

13. How much does it cost (per unit)?
    a. plastic b. glass

    c. metal d. paper e. ....

13. Do you have other job beside scavenger? Yes/No
    If Yes,:

    a. Explain about the job
    b. How long have you been working for that job?
    c. Is the job is the main or the side income?.

14. How long do you work in a day? _________________ (mention the time)
15. How long do you work in a week? _______________ (mention the day)
16. How much is your minimum income per day?
17. How much is your maximum income per day?
18. Do you put on the following equipment while you are working? (lingkari yang dipilih)
    a. gloves b. boots c. masker d. Working suit
19. Do you find the sharps (needle, knives) often?
20. Do you find medical waste (medicine, needles, tissue/bands, infuse, etc) often?
21. Do you find chemical waste (paint tin, oil bottle, spray, dll) often
22. Is there any fire incidents in landfill?

Form for waste sorting

Day	time	Plastic [kg]	Glass [-]	Metal [kg]	Paper [kg]	Others
1	Morning (..... - .....)					
	Afternoon (.....-......)					
2	Morning (..... - .....)					
	Afternoon (.....-......)					
3	Morning (..... - .....)					
	Afternoon (.....-......)					
4	Morning (..... - .....)					
	Afternoon (.....-......)					
5	Morning (..... - .....)					
	Afternoon (.....-......)					
6	Morning (..... - .....)					
	Afternoon (.....-......)					
7	Morning (..... - .....)					
	Afternoon (.....-......)					
8	Morning (..... - .....)					
	Afternoon (.....-......)					
9	Morning (..... - .....)					
	Afternoon (.....-......)					
10	Morning (..... - .....)					
	Afternoon (.....-......)					
11	Morning (..... - .....)					
	Afternoon (.....-......)					
12	Morning (..... - .....)					
	Afternoon (.....-......)					