Scenarios for Sustainable Final Waste Treatment in Developing Country

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1. Introduction

Worldwide, the waste management sector contributes approximately 3 – 5 % of total anthropogenic emission in 2005. Compared to the total emission, this percentage is relative minor [1]. 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 [2]. 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 [3]. The implementation of these waste managements can reduce emissions from other sectors of the economy such as energy, forestry, agriculture, mining, transport, and manufacturing sectors. The emission from waste management sector is mainly sourced from landfill through methane which is produced during waste degradation process [1]. Landfills have been practiced for disposing of the waste in developed and developing countries with different level of technical and safety requirements. In developed countries such as EU member states, there is decreasing trend of landfilling for the EU Landfill Directive requiring the reduction of biodegradable waste disposal in landfill [3]. Mean while, landfill is the most common method in waste disposal in developing countries though continuous efforts to promote other waste disposal methods such us recycling, incineration, mechanical and biological treatment. Unfortunately, many developing countries operate an open dump site instead of a controlled landfill [2]. 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 by discharging green house gas i.e. methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O), and nitrogen oxide (NO_x) into 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 site. 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) [4]. 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 and the government targets to reduce the total GHG emission by 26% by 2020 from 2009 level [5]. 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 [6, 7]. 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 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 [8]. 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 [9]. In controlled landfill, scavenging activity is allowed and believed as a contribution to waste reduction. Scavengers involve in Bendo landfill 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 leading to longer landfill's age and lower landfill gas (LFG) emission. 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. 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. The current composting rate is 10.33% of total biowaste.

Three different scenarios for the final waste treatment 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 problems

The study aims to analyze the scenarios for the new controlled landfill in Yogyakarta, Indonesia. The proposed scenarios are assessed based on global warming potential using

IPCC Tier 2 method suggested by [10] and sustainability as well as efficiency using emergy analysis. By assessing these scenarios, it is possible to determine the best choice for appropriate waste treatment in landfill. Considering the general current local conditions of waste management, the study is conducted with the focus on the following problems;

- 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 focuses on the following 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.

3. Method

The area of study is Yogyakarta City as a representative of a big city which has a population about 460,000 inhabitants [11]. 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 authorities in Yogyakarta to identify the general municipal solid waste 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 the local government as the landfill owner/operator and the 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 number of the scavengers is determined using sampling method and the registered scavenger in the old landfill is the population for the sample. The amount of the waste delivered to the new landfill is a function of projected population, current waste generation per capita and level of service on collection whose rate or value was presented in [9].

The goal of the survey in the old landfill was to estimate the waste reduction rate caused by the existing scavenging and composting activity in Yogyakarta City. The result of the survey was used in scenarios as a reference to estimate the net waste disposal in the new landfill. The selection of the best scenario was based on the GWP and the emergy indices. IPCC Tier 2 method was used to estimate the GWP, while emergy analysis was applied to calculate the emergy indices.

4. 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 1) proposed by [12].

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

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

5. Methane generation calculation

The methane emission during the new landfill time is estimated by means of time series data on waste disposal from 2013 until 2028. Population from 2013 until 2028 is projected using equation 2 [13].

$$Pn = Po(1 + r)^n \tag{2}$$

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 3 suggested by [10].

$$CH_{4Emiss} = \left[\sum_{x} CH_{4generated_{x,T}} - R_T \right] * \left(1 - OX_T\right) \quad (3)$$

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

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.

6. 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). Some default values proposed by [10] 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 9000 - Rp 10,000 in 2010.
- Waste density is assumed 400 kg/m^3 based on the average domestic waste density in Indonesia proposed by [14]. 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 incomplete data of waste tonnage disposed of in the old landfill in 2008 and 2009. 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.

7. Scenarios for future landfill operation in Yogyakarta

The results from the observation of old landfill are also used as a reference in determining the alternatives. The scenarios include the calculation of environmental parameters (GWP and emergy values) from final waste treatment. The assumptions mentioned above are conditioned also to the scenario. 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 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. Like Bendo landfill, the new landfill accepts the waste not only from Yogyakarta 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.

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 treatment 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. 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.

8. 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 is calculated using Equation 3. Though the existence of the regular soil covering (once a month) in Scenario 1 and Scenario 2, the variable of oxidation factor is assumed 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 [15]. 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 4 and Equation 5 respectively [16]. The methane emission is then converted into emissions of CO_2 [CO_{2eq}].

$$C_{CH_4} = \left(1 - \eta_{col}\right) * U_{CH_4} \tag{4}$$

$$C_{CO_2} = U_{CO_2} + \left(\eta_{col} * U_{CH_4}\right) \tag{5}$$

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)

9. 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 6 – Equation 9 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 1. 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 [17, 18].

$$\text{EYR} = \text{Emergy recovery/emergy investment} \tag{6}$$

$$\text{Net Emergy} = \text{Emergy recovery} - \text{Emergy investment} \tag{7}$$

$$\text{ELR} = \text{NR+NP+RP/RR} \tag{8}$$

$$\text{ESI} = \text{EYR/ELR} \tag{9}$$

10. Results and findings

The waste disposed of in the old landfill sources from the municipal solid waste (MSW) in Yoyagkarta and partly from Bantul and Sleman County. The MSWM in the area of study is characterized by the existence of informal waste management in household level (door to door collection), community level (transfer point collection) and city level (separation in landfill site). Only the involvement of scavenger in landfill was taken into account in this study. The composting centers accept approximately 25 ton/day biowaste and can produce up to 8.3 ton/day which equals to 10.33% biowaste reduction in landfill. The rest of the organic waste and other waste constituents are dumped in the landfill as described in Figure 1.

There are 400 scavengers registered in the old landfill and using Equation 1 there should be 200 samples (sample error of 5%). However, during the preliminary survey, it has been identified that only 45 scavengers can be chosen as respondent. Each scavenger separate approximately 54.3 kg/day and 52.05 kg/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/day and 0.004 kg/day respectively. The waste reduction of the recyclable materials in landfill through 45 scavengers are 7.54%, 12.87%, 0.15% and 0.03% for plastic, paper, glass and metal respectively. The recyclable wastes are sold to the middle man before it is transported to other parties, such as metal manufactures, recycle centers of plastic and paper. The glass bottles are usually transferred to the home industries.

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 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 to the environment.
Emergy Sustainability Index	ESI	ESI=EYR/ELR	The highest the ratio, the more sustainable.

Table 1. Emergy values and emergy indices analyzed in this study

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 scavengers is shown in Table 2.

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

Table 2. Waste reduction at Bendo landfill

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 disposal at the rate of 1.48%. The income generated from scavenging is about $2.51/p/day or total is $62.75/day. Income comes mainly 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.

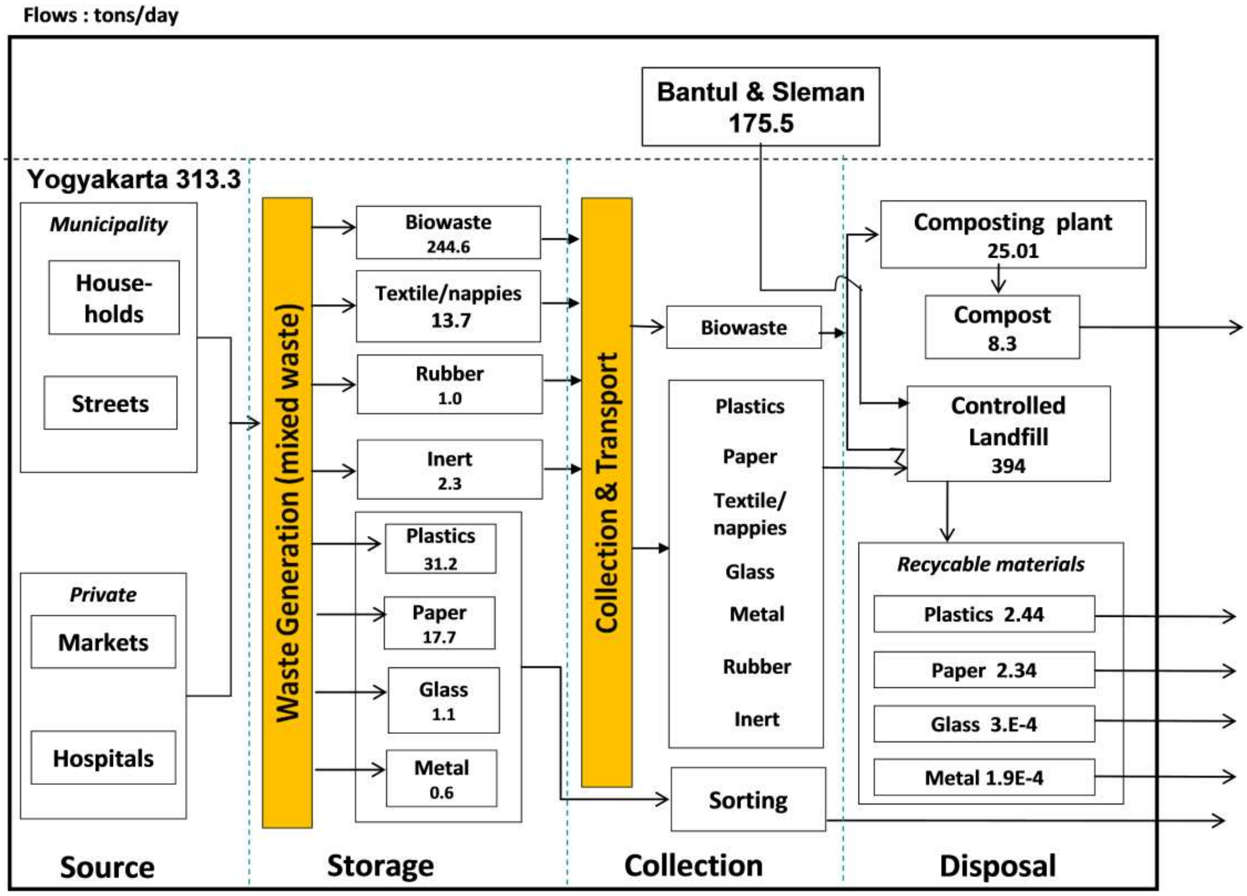

Figure 1. Waste stream in boundary system

Meanwhile, the composting can generate income of $163.5/day if it is assumed that the compost is sold with the current compost price in the market ($0.021/kg) as presented in Table 3.

Materials	Mass [kg/p/d]	Price [Rp/kg]	Price [US$/kg]	Income [US$/p/day]	Income [US$/day]
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				**2.51**	
total sample(45 scavengers)					62.75
From Composting centers					
Compost [kg/d]	7,766	200	0.021		163.5

Table 3. Income from waste sorting and composting centers in Yogyakarta

The population and waste generation projection is initiated from 2013 using the number of population in 2012. The average population growth rate is 1.51% [19] and the average waste generation rate is 1.61% [20]. 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 waste generation per capita. The result is presented in Figure 2.

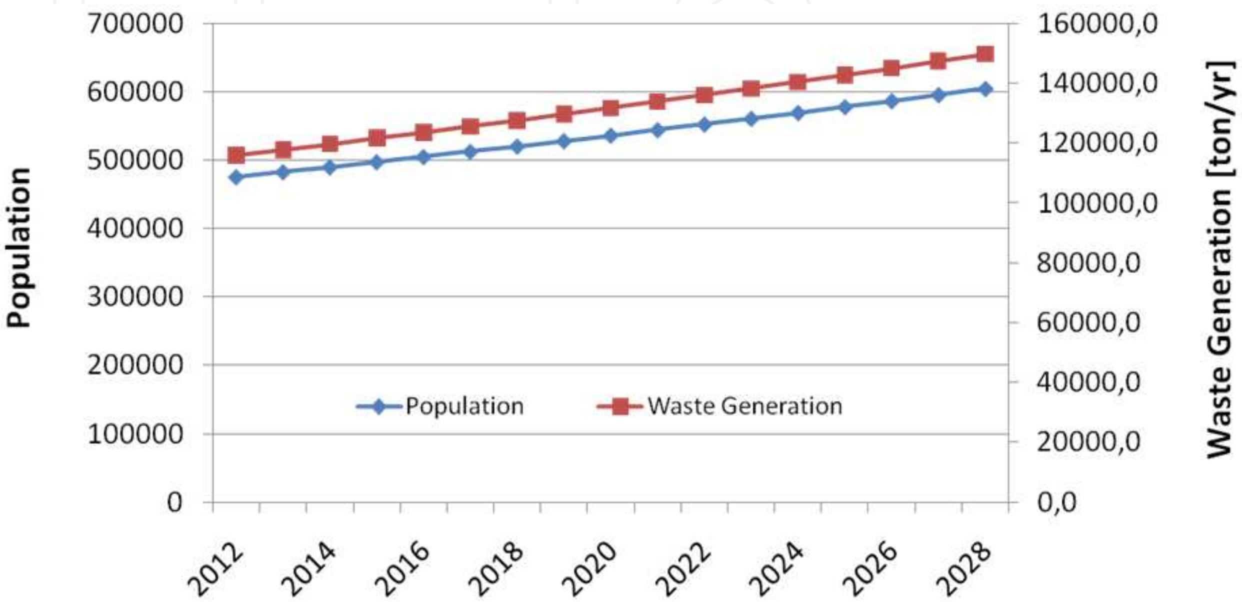

Figure 2. Projection of population and waste generation in Yogyakarta City

The projection of waste disposal in landfill is made referring to the landfill opening year in 2013 and duration for 15 years. Figure 2 shows the projection of waste disposed of in the new landfill with the level of service (LoS) on collection of 70%.

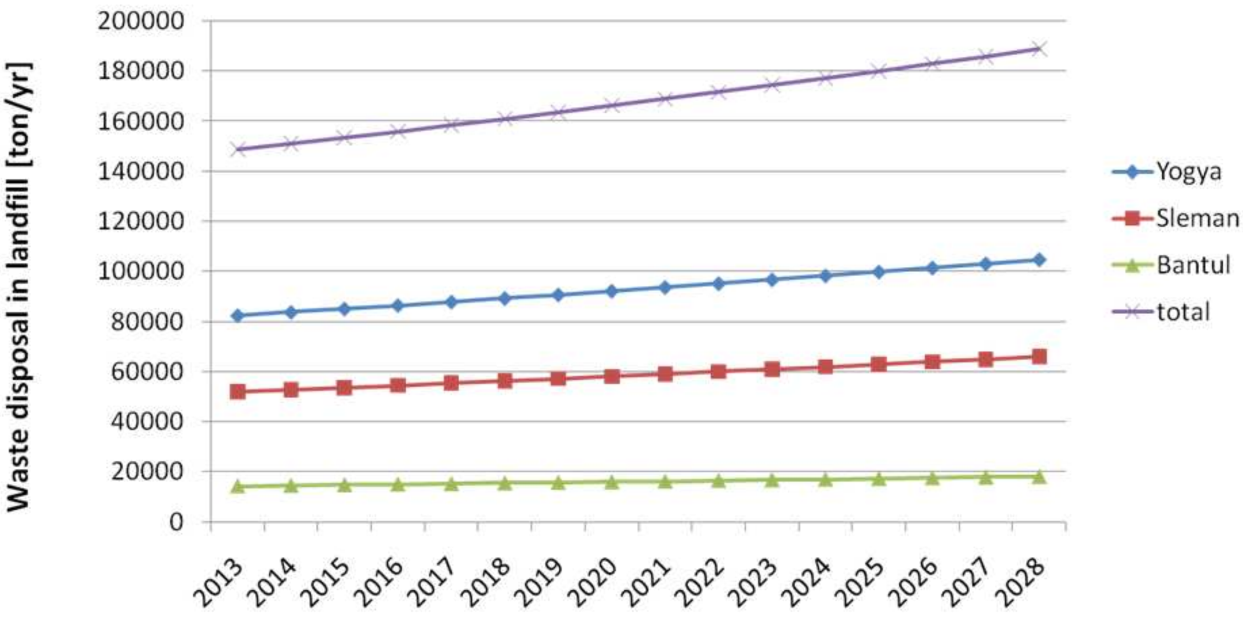

Figure 3. Waste disposal in the new landfill

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.

11. 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. 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 emission from the 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 [21], aerobic decomposition in composting plant results emission of CO_2 and H_2O. Methane can be also generated in anaerobic pockets within a compost pile due to the heterogeneous nature of compost pile [22]. Nevertheless, some studies showed that the majority of methane emission oxidizes to CO_2 in aerobic pockets and near the surface of the compost pile, so that methane emission can be neglected [23, 24]. The methane generation calculation is done with the assumption that methane will be generated for 47 years (2013 – 2060).

The emergy indices are derived from the calculation of emergy input and output within the boundary including the collection, landfill site and composting center.

11.1. 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 collected in the landfill and 10.33% of biowaste is treated in the 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. If there is no measure of waste reduction through scavenging and composting, 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 measure (no scavenging and composting). Figure 4 describes the comparison of the methane emission from the new landfill during its operational time between conditions with waste reduction through scavenging and composting and without it.

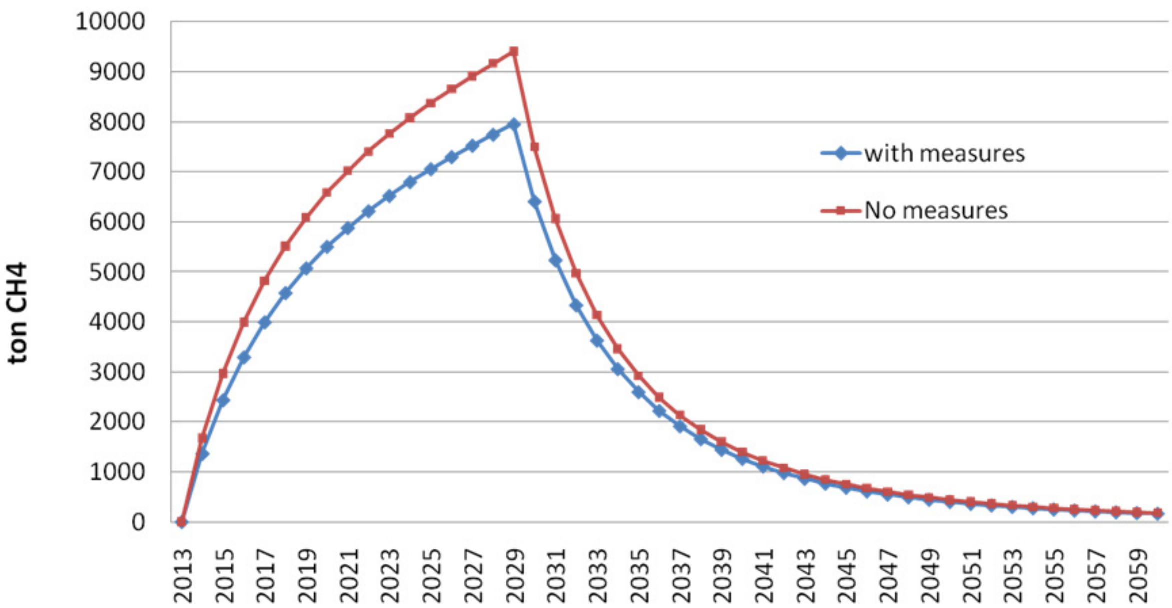

Figure 4. Methane emission from the new landfill based on Scenario 0

11.2. 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 and waste reduction measure is implemented through composting and scavenging. 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 [25]. 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 target of increasing capacity makes sense as there is abundant organic waste and human resources. However, it requires additional equipment and facilities consequently. The six fold capacity increase requires 31% emergy investment increase as presented later in Table 6 – 8 indicating that it requires relatively restrained 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 ton to 3.26E+06 tons. The total amount of methane emission from the new landfill is about 1.02E+05 ton CH_4 or 2.16E+06 ton CO_{2eq}. Figure 5 describes the methane emission from the new landfill during its operational time based on Scenario 2.

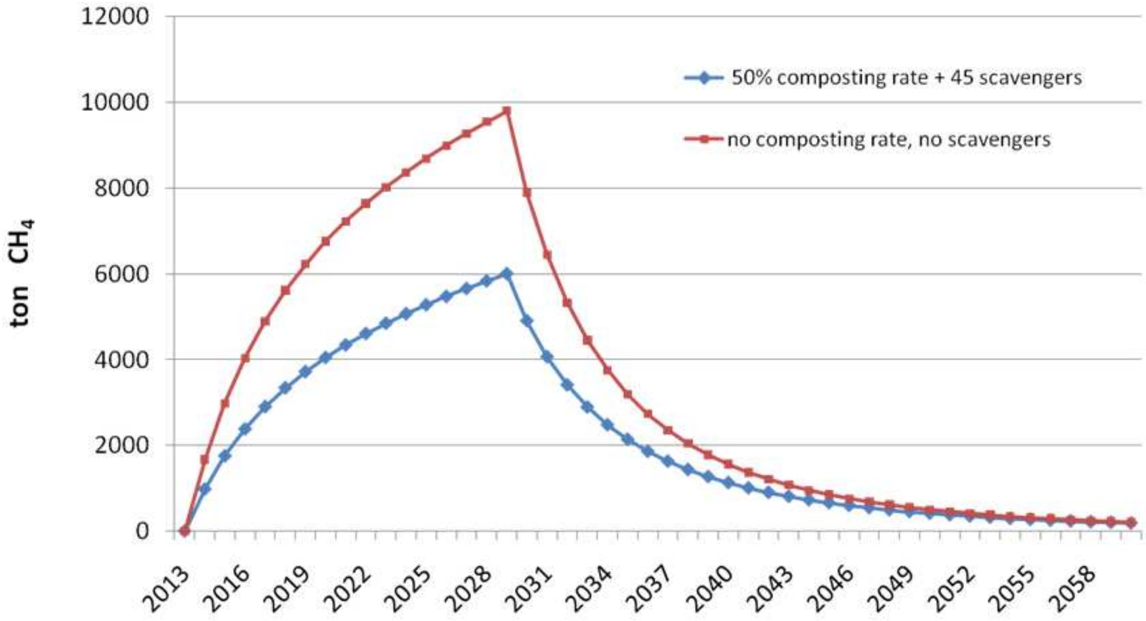

Figure 5. Methane emission from the new landfill based on Scenario 1

11.3. Scenario 2: LFG flaring scenario

In Scenario 2 scenario, 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%.

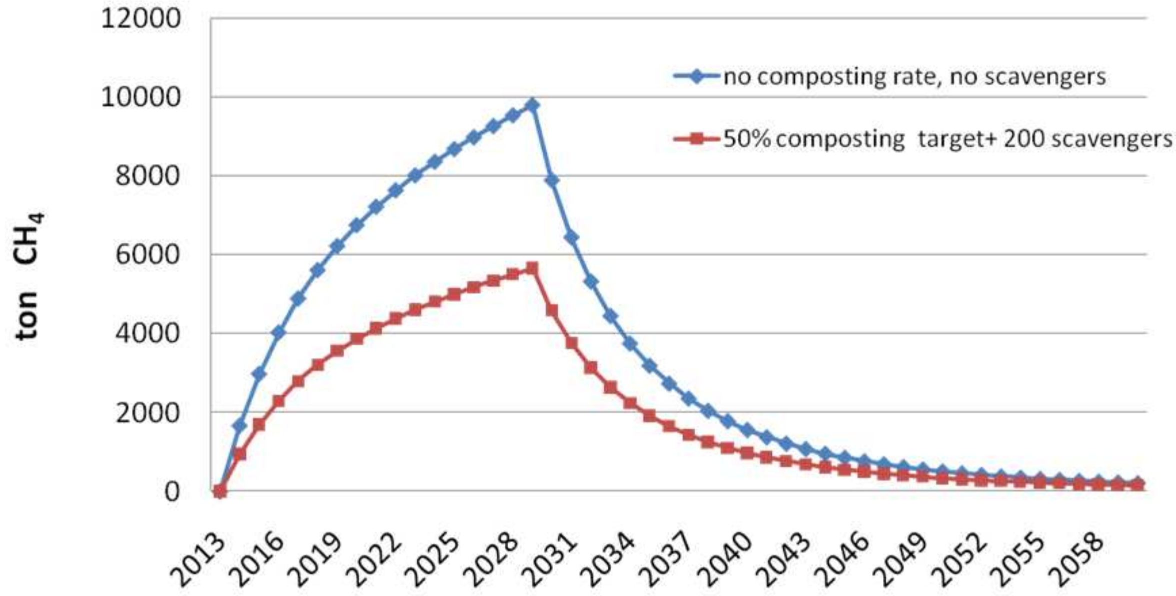

Figure 6. Methane emission from the new landfill based on Scenario 2

The average collection system cost for landfills with flaring system is assumed based on the value proposed by [16] which includes flaring costs. The initial cost for the collection system is US$ 628,000 and the O&M is US$ 89,000/yr. In Scenario 2, the methane emission from landfill will be 2.00E+06 ton CO_2eq as showed in Figure 6. The composting rate is the same as in the Scenario 1. Therefore, composting capacity is 230.5 tons/day and the compost production is 76 tons/day

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 biowaste 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 biowaste 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 7. 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% biowaste reduction through composting has decreased the emission considerably.

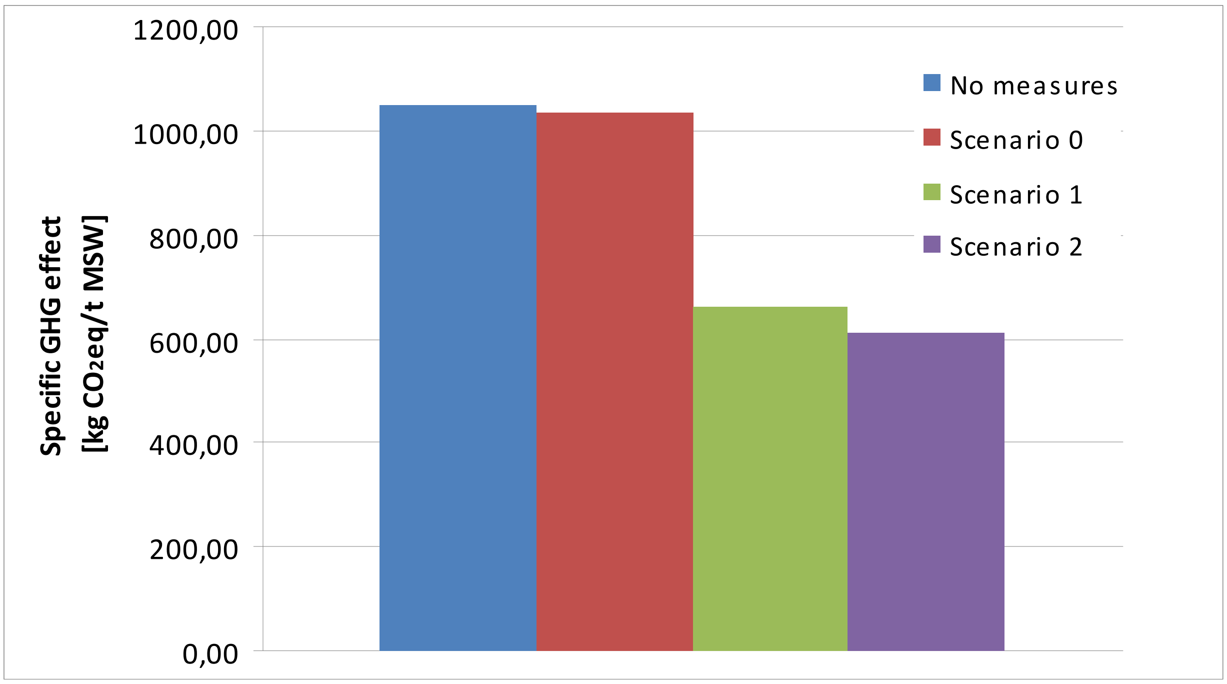

Figure 7. Specific GHG emission comparison of each scenario

The comparison between the three scenarios in terms of GWP demonstrates that the scavenging and composting play role in waste reduction brings the GWP reduction. 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 4 and Table 5.

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 (calculated)				
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_2eq]	-	-	-	1,001,002
Specific GHG effect [kg CO_2eq/ ton MSW collected]	1,049	1,034	661	613

Table 4. Summary of comparison during landfill life

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
Biowaste [ton/d]	25.01	36.76	230.5	230.5
Biowaste [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

Table 5. Summary of comparison for composting

12. Emergy analysis of the scenario 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 an emergy diagram. The emergy system diagram describes the emergy flows into and out of the system in the form 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 is presented in emergy system diagram.

3. Calculation of matter and energy flows supporting the scenario All inputs in the system were 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 6 – 9. The amount of the available emergy (exergy) is calculated based on the primary and secondary data.
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 [26, 17].
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.

12.1. 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 and renewable, non renewable 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) [27]. For the waste material just stored in the landfill, there is no reason for assigning its transformity. The outputs are the products produced during the process including also the good/services that are sold in the market. 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 in landfill. 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 biowaste 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.

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 8. Meanwhile, Figure 9 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 gases 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 sold into emergy units, using the emergy-to-money ratio in Indonesia, 2.06E+13 seJ/$ [28]. As the study is limited to the emission from the landfill, the emission from the WWTP and composting process will not be considered.

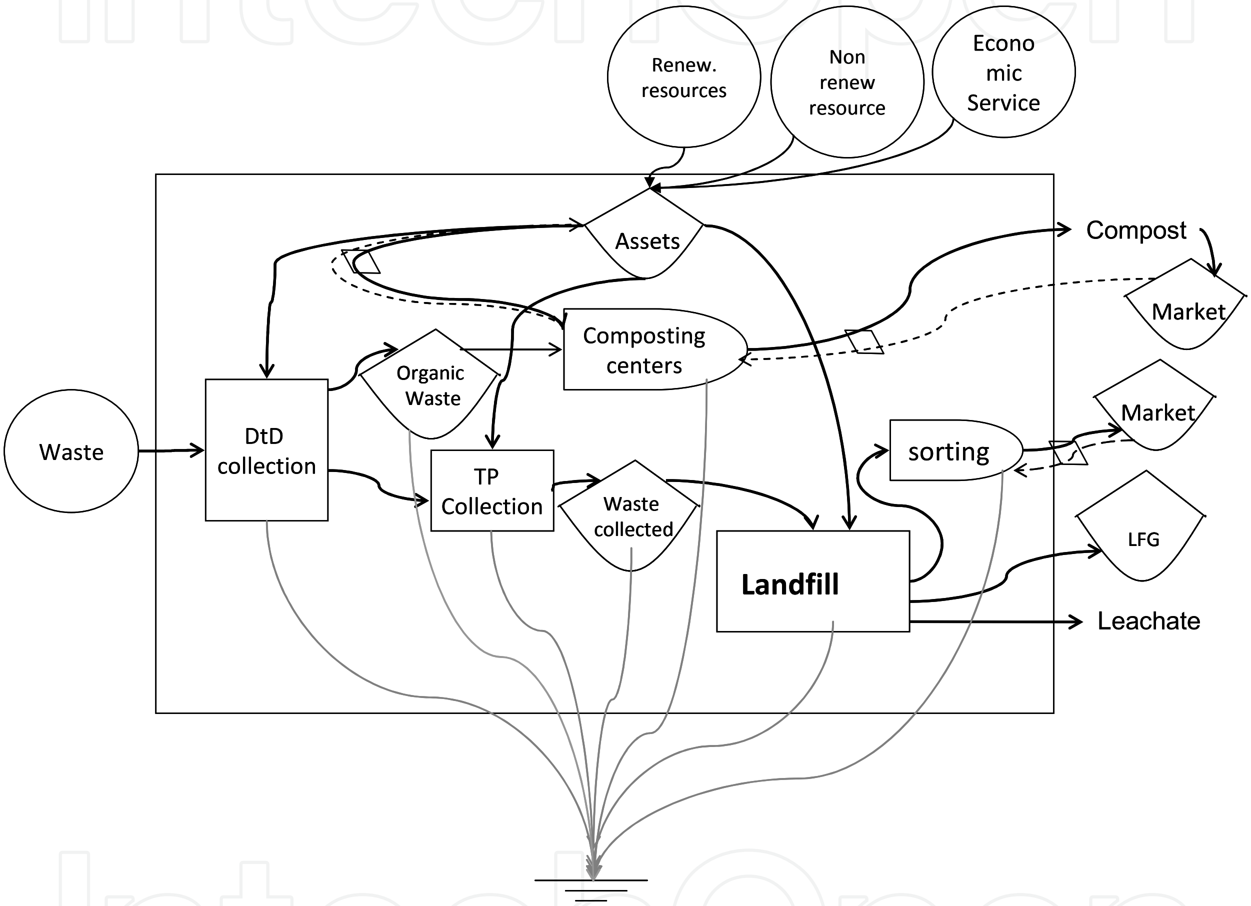

Figure 8. Emergy system diagram of Scenario 0 and Scenario 1

After describing the emergy flow in the diagram, the calculation of the total emergy is conducted and presented in table of emergy. Table 6 – 8 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, less than 1% (Figure 10 – 12).

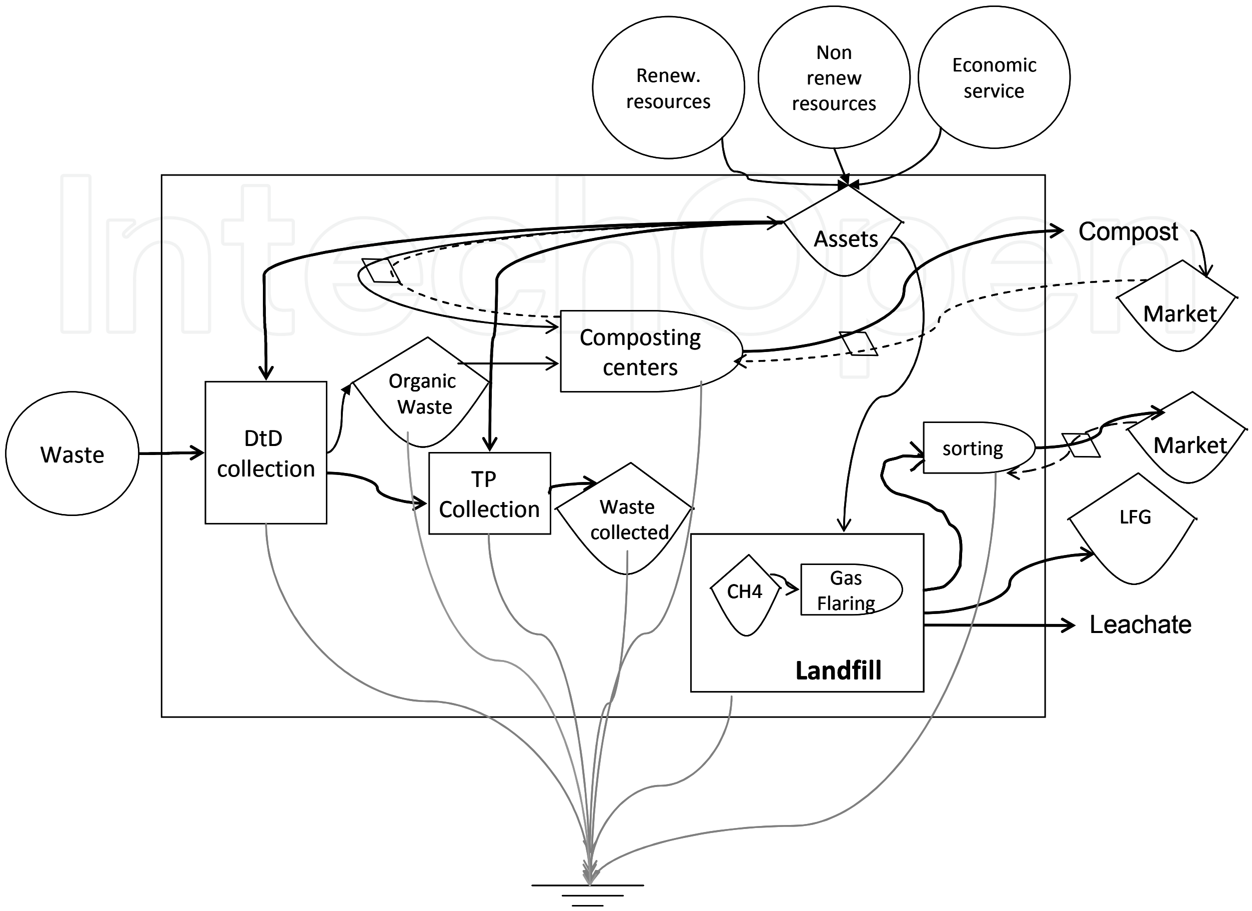

Figure 9. The emergy system diagram of Scenario 2

Table 6 and Figure 10 (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 the less amount of disposed waste requires less quantity of equipment, fuel, labor and other capital causes less input of emergy.

Table 7 and Figure 11 (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 generated in composting centers. 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.

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	[29]	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	[29]	**7.27E+15**	**4.06E+04**
Non renewable resources in collection process purchased (NP)							
4	Handcart	g	1.74E+07	5.91E+09	[30]	1.73E+17	9.67E+05
5	Vehicles	J	951E+11	7.76E+09	[31]	1.24E+22	6.92E+10
6	Fuel	J	2.73E+12	6.60E+04	[32]	3.03E+17	1.69E+06
7	Water	g	3.65E+09	6.64E+05	[29]	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	[28]	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	[32]	2.73E+23	1.52E+12
11	Material for waste final covering	g	6.21E+12	1.68E+09	[32]	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	[30]	1.28E+21	7.15E+09
13	Fuel	J	1.35E+12	6.60E+04	[32]	1.50E+17	8.37E+05
14	Electricity	J	3.03E+10	1.60E+05	[17]	4.85E+15	2.71E+04
15	Vehicles	J	8.21E+10	7.76E+09	[31]	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	[28]	6.94E+19	3.87E+08
18	Annual O&M cost incl. Labor.	$	1.75E+06	2.06E+13	[28]	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	[30]	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	[17]	3.05E+15	2.13E+05
22	Fuel	J	3.25E+10	6.60E+04	[32]	3.60E+15	2.52E+05
23	Labor	J	1.83E+12	4.63E+06	this	8.45E+18	5.90E+08

					study		
						8.46E+18	**5.91E+08**
Economic services (NP)							
24	Investment cost	$	3.45E+03	2.06E+13	[28]	7.11E+16	4.96E+06
25	Management cost	$	5.94E+05	2.06E+13	[28]	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 6. Emergy flows of scenario 0

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	[29]	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	[29]	**7.27E+15**	**3.34E+04**
Non renewable resources in collection process purchased (NP)							
4	Handcart	g	1.86E+07	5.91E+09	[30]	1.84E+17	8.47E+05
5	Vehicles	J	1.05E+12	7.76E+09	[31]	1.36E+22	6.27E+10
6	Fuel	J	3.14E+12	6.60E+04	[32]	3.48E+17	1.60E+06
7	Water	g	5.48E+09	6.64E+05	[29]	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	[28]	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	[32]	2.73E+23	1.25E+12
11	Material for regular and final covering	g	3.11E+13	1.68E+09	[32]	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	[30]	1.28E+21	5.88E+09
13	Fuel	J	4.06E+12	6.60E+04	[32]	4.50E+17	2.07E+06
14	Electricity	J	3.03E+10	1.60E+05	[17]	4.85E+15	2.23E+04
15	Vehicles	J	2.08E+11	7.76E+09	[31]	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	[28]	6.94E+19	3.19E+08
18	Annual O&M cost incl. Labor.	$	1.94E+06	2.06E+13	[28]	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	[30]	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	[17]	3.05E+15	1.40E+04
22	Fuel		5.42E+10	6.60E+04	[32]	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	[28]	7.11E+16	3.27E+05
25	Management cost	$	7.65E+05	2.06E+13	[28]	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 7. Emergy flows of the scenario 1

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	[29]	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	[29]	**7.27E+15**	**3,34E+04**
Non renewable resources in collection process (NP)							
4	Handcart	g	1.86E+07	5.91E+09	[30]	1.84E+17	8.47E+05
5	Vehicles	J	2.50E+12	7.76E+09	[31]	3.26E+22	1.50E+11
6	Fuel	J	3.14E+12	6.60E+04	[32]	3.48E+17	1.60E+06
7	Water	g	5.48E+09	6.64E+05	[29]	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	[28]	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	[32]	2.73E+23	1.25E+12
11	Material for regular and final covering	g	3.11E+13	1.68E+09	[32]	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	[30]	1.28E+21	5.88E+09
13	Fuel	J	4.06E+12	6.60E+04	[32]	4.50E+17	2.07E+06
14	Electricity	J	3.03E+10	1.60E+05	[17]	4.85E+15	2.23E+04
15	Vehicles	J	2.08E+11	7.76E+09	[31]	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	[28]	8.23E+19	3.78E+08
18	Annual O&M cost incl. Labor.	$	1.92E+06	2.06E+13	[28]	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	[30]	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	[17]	3.05E+15	1.40E+04
22	Fuel		5.42E+10	6.60E+04	[32]	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	[28]	7.11E+16	3.27E+05
25	Management cost	$	7.65E+05	2.06E+13	[28]	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				

Table 8. Emergy flows of the scenario 2

Table 8 and Figure 12 (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.

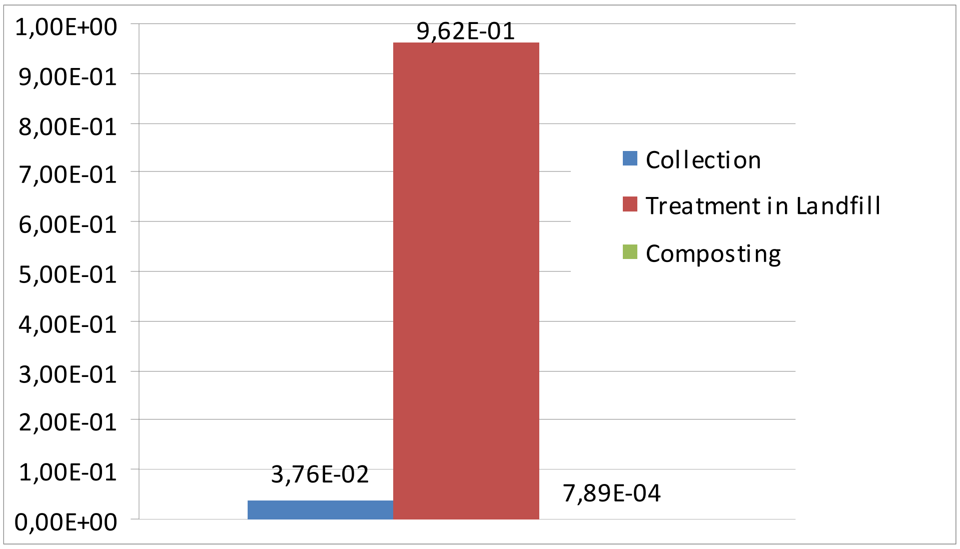

Figure 10. Share of emergy investment in Scenario 0

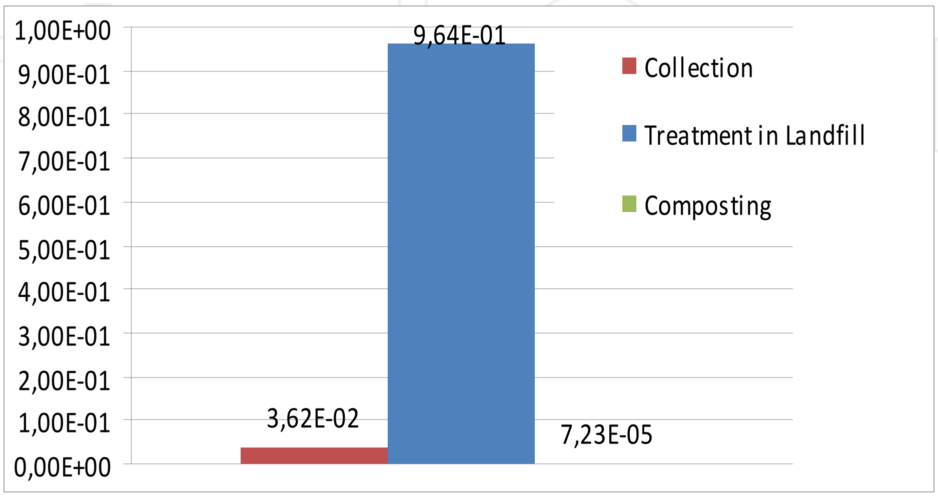

Figure 11. Share of emergy investment in Scenario 1

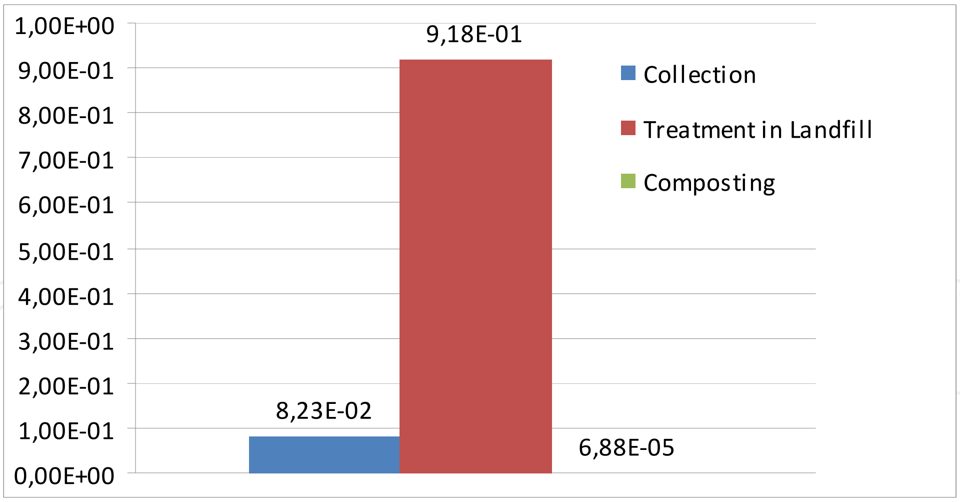

Figure 12. Share of emergy investment in Scenario 2

As mentioned above, scavenging and composting are the source of emergy recovery. Table 9 – 11 describes the emergy recovery from each scenario. The matter/ money recovery is calculated by dividing the product for the amount of waste treated [33]. Emergy recovery is calculated by multiplying energy or matter 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 2.1% nitrogen(N), 1.6% phosphorus (P), 1.1% potassium (K) [34]. The rest is the remaining part assumed as soil [29]. The calculation of emergy in composting uses the transformity of the fertilizer component (N, P, K) and the land cycle from [32].

	Product	Unit	Matter or money recovery	Unit	Transformity [seJ/unit]	Emergy recovery [seJ/g]
Composting	**4.72E+09**	**g**	**3.30E-01**	**g/gMSW**		**4.46E+08**
N(2.1%)	2.08E+08	g	1.45E-02	g/gMSW	4.62E+09	3.20E+07
P(1.6%)	5.20E+07	g	3.63E-03	g/gMSW	1.78E+10	9.40E+07
K(1.1%)	8.50E+07	g	5.94E-03	g/gMSW	1.74E+09	6.32E+07
Soil	4.38E+09	g	3.06E-01	g/gMSW	1.00E+09	3.14E+08
Scavenging	**4.35E+04**	**$**	**2.43E-07**	**$/gMSW**	**2.06E+13**	**5.00E+06**
Total						**4.51E+08**

Table 9. Emergy recovery of Scenario 0

The calculation of emergy recovery presented in Table 9 – 11 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 1.27E+09 seJ/gMSW. Scenario 0 and Scenario 1 can generate the relative same amount of emergy saving (4.51E+08 seJ/gMSW) although the emergy input in Scenario 0 is higher than Scenario 1. The same scavenging rate and the higher composting rate of Scenario 1 with the higher LoS compared to Scenario 0 cause this, since matter recovery depends not only on the product but also the waste treated.

	Product	Unit	Energy/matter recovery	Unit	Transformity [seJ/unit]	Emergy recovery [seJ/g]
Composting	**2.78E+10**	**g**	**3.30E-01**	**g/gMSW**		**4.46E+08**
N(2.1%)	1.22E+09	g	1.45E-02	g/gMSW	4.62E+09	3.20E+07
P(1.6%)	3.05E+08	g	3.63E-03	g/gMSW	1.78E+10	9.40E+07
K(1.1%)	5.00E+08	g	5.94E-03	g/gMSW	1.74E+09	6.32E+07
Soil	2.57E+10	g	3.06E-01	g/gMSW	1.00E+09	3.14E+08
Scavenging	**4.35E+04**	**$**	**2.00E-07**	**$/gMSW**	**2.06E+13**	**4.12E+06**
Total						**4.51E+08**

Table 10. Emergy recovery of Scenario 1

	Product	Unit	Matter or money recovery	Unit	Transformity [seJ/unit]	Emergy recovery [seJ/g]
Composting	**2.78E+10**	**g**	**3.30E-01**	**g/gMSW**		**4.46E+08**
N(2.1%)	1.22E+09	g	1.45E-02	g/gMSW	4.62E+09	3.20E+07
P(1.1%)	3.05E+08	g	3.63E-03	g/gMSW	1.78E+10	9.40E+07
K(1.8%)	5.00E+08	g	5.94E-03	g/gMSW	1.74E+09	6.32E+06
Soil	2.57E+10	g	3.06E-01	g/gMSW	1.00E+09	3.14E+08
Scavenging	**8.70E+06**	**$**	**4.00E-05**	**$/gMSW**	**2.06E+13**	**8.24E+08**
Total						**1.27E+09**

Table 11. Emergy recovery of Scenario 2

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 9 – 11, the emergy indices of each scenario is calculated and presented in Table 12.

	S0	S1	S2
Total solar emergy [seJ/y]	**3.03E+23**	3.78E+23	3.97E+23
Emergy Investment [seJ/g MSW]	1.84E+12	**1.74+12**	1.82E+12
Emergy recovery [seJ/g MSW]	4.51E+08	4.51E+08	**1.27E+09**
EYR	2.45E-04	2.59E-04	**6.96E-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	4.95E-10	4.84E-10	**5.20E-09**

Table 12. Emergy evaluation of Scenarios

The results of the analysis demonstrate that Scenario 0 contributes the lowest solar emergy input caused by the lower compliance of landfilling standards and the less amounts of waste disposal and treatment. Scenario 2 demands the highest emergy input because the construction of LFG collection system needs significant additional cost. Nonetheless, the increasing amount of waste collected affects the lower emergy investment compared to Scenario 0. Meanwhile, Scenario 1 needs the lowest emergy investment. The lower emergy input than Scenario 2 for the absence of LFG collection system and the higher amount of waste disposal and treatment than Scenario 0 are the rationales for this. Scenario 2 generates the highest emergy recovery for the higher scavenging rate than Scenario 1 and the higher composting rate than Scenario 0. It shows that the application of LFG collection system has an effect on the entire waste treatment efficiency. The highest EYR is generated by Scenario 2 indicating the most suitable alternative in recovering emergy from MSW though the highest emergy input. All scenarios have the negative value of Net Emergy. It means that none of the scenarios is capable to save the greatest quantity of emergy per unit weight of MSW treated as the emergy investment is higher than the emergy recovery. However, Scenario 1 supplies relatively higher benefits than two other scenarios because it has the 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 compared to other scenarios. The highest EYR and the lowest ELR is the reason for the highest ESI for Scenario 2. The highlighted value in Table 12 is the value that meets the criteria of each parameter.

13. Conclusion

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 biowaste 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 biowaste prevented from disposal in landfill.

Three scenarios of final waste treatment have been evaluated. 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. The involvement of scavengers in the new landfill is considered in all scenarios since the evaluation of the old landfill indicates that scavenging has contributed waste and LFG emission reduction. The evaluation includes 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. Biowaste 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 covers the landfill with open flare system reduces 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. In all scenarios, landfilling process needs the highest emergy investment which is mainly contributed by emergy input from fuel and plant construction. The positive emergy recovery is contributed by composting and scavenging which generates income. Therefore, the new landfill should not eliminate scavenging totally. The evaluation of emergy indices shows that Scenario 0 contributes the lowest solar emergy input, while Scenario 1 demands the lowest emergy investment and provides the highest Net Emergy. Furthermore, Scenario 2 generates the highest emergy recovery, the highest EYR, the lowest ELR and the highest ESI. Table 13 presents the environmental parameters analyzed in the study.

	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

Table 13. The evaluation of the scenarios

According to the value of the environmental parameters analyzed in the study, Scenario 2 shows the best result since it has more environmental parameters which fulfill the criteria. It is characterized by high EYR and low ELR which is an indication of sustainability and the highest emergy recovery implying the efficiency though the relative high emery investment. Hence, it implies that Scenario 2 is the best alternative for final waste treatment scenario in Yoyakarta City.

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