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Emergy Analysis of Waste Treatment in Small Scale Final Solid Waste Disposal Site

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Abstract. The enactment of National Waste No. 18/2008 by The Government of Indonesia (GoI) is the opportunity for the local governments to improve the Level of Service (LoS) of Municipal Solid Waste Management (MSWM). The Law requires the local government to implement the environmentally friendly solid waste management including the waste treatment in landfill as a final solid waste disposal site (SWDS). Talangagung landfill located in Malang regency is a small scale landfill which is operated as a controlled landfill to meet this requirement. The landfill was opened in 2009 and equipped with the biogas collection system. Although the landfill covers only 2 ha, it supplies 165 households adjacent to the landfill with biogas. All households use the biogas for cooking as a substitute of kerosene and liquid petroluem gas (LPG). It was obvious that the utilization of the landfill biogas gives benefits to the community. Therefore, the study aims to calculate the transformity of landfill biogas as the coefficient describing the energy accumulation requiring producing the biogas. The calculation of the transformity was conducted using emergy analysis. Beforehand, methane generation was calculated using the methodology proposed by IPCC. The calculation came to result that total production of methane for 20 years is 16,466.23 tons of CH_4 or 345,790.92 tons of CO_{2e}. . However, the landfill biogas utilization is only 25.47 tons of CH_4 or only about 1.16 percent of the total potential biogas. The involvement of scavenger in separating the recyclable materials in landfill reduces the total waste mass disposed. The emergy calculation shows that the solid waste management in small scale final solid waste disposal site requires 2.92E+21 seJ/year.

Keywords: Emergy-analysis, methane-generation, landfill, biogas.

1. Introduction

In 2005, waste sector contributed globally about 3 percent to 5 percent from total anthropogenic emission. It is predicted that the amount is increasing along with global population growth. Compared to the total emission, the amount is actually low. However, if there are no measures to decrease the emission from waste sector, the more intensively environmental degradation will occurred in the future [1]. Therefore, it is required to implement some measures to reduce the emission through waste management hierarchy which is disposal as the lowest level and prevention as the highest level. The main contributor of emission from waste sector is waste treatment in landfill [2]. In landfill, the waste is stored and the dynamics of its degradation is controlled to avoid emission with adverse effect such as chemical effluent into atmosphere, underground water bodies, and soil. Consequently, landfills are not the most suitable waste treatment and should be replaced by other waste processing method. Yet, landfill is commonly used as a waste processing facility in Indonesia and most of them are open dump sites affecting adversely the environment. Open dumping practice can gradually reduce the land and it causes water and soil pollution as well as air pollution because the main releases from a landfill system are biogas and leachate. Biogas

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comprises 60 percent greenhouse gas CH_4 and 40 percent of CO_2, where CH_4 has 25 times higher global warming potential (GWP) than carbon dioxide [3], [4].

The enactment of National Waste Law No. 18/2008 in May 2008 requires all local governments in Indonesia to implement environmentally friendly waste management including the waste treatment in landfill as stated in article 22 and 44 [5]. Thus, the Regency of Malang which is responsible for activities in Talangagung landfill has to operate the landfill which meets the requirements. Therefore, the local government operates the Talangagung landfill as a controlled landfill equipped with biogas collection system. Currently, the landfill can distribute the landfill biogas to 165 households adjacent to the landfill site. The gas is used for cooking to replace the use of liquid petroleum gas (LPG). Biogas utilization provides benefit to the community, since it decreases the fuel expenses, increase the surrounding environment quality and improve the environmental awareness. Therefore, the investigation of the investment for controlled landfill operation is required by analyzing the emergy demanded to manage the solid waste stored in small scale controlled landfill. Controlled landfill construction and operation need monetary investments, as well as material and energy investments. Currently there is no local transformity value representing the specific characteristic of the biogas from small scale controlled landfill. The result of the investigation can contribute to better accounting of emergy for Talangagung landfill as well as other landfills in Indonesia. Moreover, it can estimate the source input required to treat per unit mass waste transported to Talangagung landfill for development in the future.

All environmental work that sustains a specific system can be quantified. The different system inputs are calculated using common basis according to their time and territorial characteristic [6]. Furthermore, the qualities generated in both the ecological and the economic system is taken into account. The evaluation of the resources required and generated by the process is based on principles for organization and optimisation of self-organizing systems which is developed out of theories in ecosystem ecology. Some previous studies have used emergy analysis to evaluate the waste treatment. A new emergy analysis method for reuse and recycling and waste treatment was proposed by [7]. [8] conducted research using emergy analysis method to evaluate the waste treatment in industrial systems, while [9] determined waste options and strategies using emergy analysis. Emergy analysis has been also used for calculating investment on recycle of building materials [10], [11]. Furthermore, these studies have introduced some several environmental indicators in calculating the emergy [12].

2. Material and Methods

2.1. Data Collection

Data were collected through primary and secondary survey conducted from July until November 2014. Questionnaires were distributed to the respondents and interview with some key persons was conducted to get more accurate data. The number of the sample is determine using Eq.1

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

The respondents for this research are scavengers working in the landfill as well as persons in local government who are responsible for waste management. Data on municipal solid waste were collected from waste authorities in Malang Regency including the waste characteristic, the rate of waste generation, operational cost, the users of biogas and level of service (LoS). Secondary data on waste were mainly sourced from statistics on waste management, City's Profile and waste status report. Primary data was collected by means of questionnaires to provide more recent data and through interview in order to follow-up the questionnaires answered by the respondents and to get in-depth information related to landfill operation. Data on waste characteristic is attained from the authority since there was no field survey to measure the waste composition.

There are 15 scavengers in the study area separating paper, cardboard, rubber, plastic, metal, textile, and glass. There is no increasing number of scavengers until 2028. Thus, the reduction of waste by scavengers is constant.

The waste composition is required to calculate the methane fraction in landfill biogas using stoichiometric equation because there is no field measurement of biogas composition. The amount of the methane generated in the landfill is calculated using Eq.2

$$CH_{4generated} = DDOC_{decompT} * F * 16/12 \tag{2}$$

Projection of methane gas is calculated based on the projection of population and level of service (LOS) in Malang. Projection of waste volume is made for the next 20 years starting from 2009.

2.2. Data Calculation

The total waste mass is measured by calculating the number of dump trucks entered the landfill during the observation because there is no daily weighing in the landfill. The multiplication of the number and the volume of the trucks equals to the total waste volume per day. The conversion from volume to mass was conducted using the typical loose waste density in Indonesia [13]. Meanwhile, the waste mass of each waste type is calculated based on the waste composition. Furthermore, the emission calculation is conducted using the Tier 1 of IPCC methodology. However, some parameters are from local values such as methane fraction, waste composition and methane emission factor.

The emergy of waste management in Talangagung landfill was calculated through the following procedures:

1. Identification system boundary emergy.
2. Making emergy diagram depicting the flow in and out of emergy in the form of the transfer of energy and materials.
3. Calculating the flow of matter and energy that supports emergy system. The amount of available energy is calculated based on secondary data and primary data.
4. Changing the input units of matter and energy into solar emergy Joules (seJ) using transformity and the value recalculated using the new base value biosphere that equals to 15.84E+24 seJ/ year [6], [14], [15].
5. Calculate total emergy of solid waste treatment in Talangagung landfill (seJ).

Emergy calculations can be performed if the input, process, and output of emergy is identified in advance and arranged in a schematic diagram called emergy diagram. Emergy input in the study includes resources (SD) renewable obtained free of charge (free renewable energy), renewable SD purchased (purchased renewable energy), and non-renewable primary purchased (purchased non-renewable energy).

3. Results and Discussions

3.1. Municipal Solid Waste in Malang Regency

Malang is located in East Java and has population of approximately 894.653 persons in 2012. Based on population, Malang Regency is a big city and according to the waste law No. 18/2008 [16], operational system in this landfill should be sanitary landfill. However, based on interview with the local government, operational system in Talangagung Landfill is controlled landfill. Waste generation is also increasing along with population growth. The population growth in Malang Regency is 1.4 percent per year [17]. According to the calculation, waste generation is increasing 1.4 percent per year.

Municipal solid waste (MSW) generation in Malang Regency is estimated around 420 ton/day and Level of Service (LoS) is 56 percent in 2012. Most of the waste dumped in Talangagung landfill is organic content (about 64 percent) and 35.1 percent moisture content. The waste composition influencing the waste properties in Malang Regency is shown in Fig. 1.

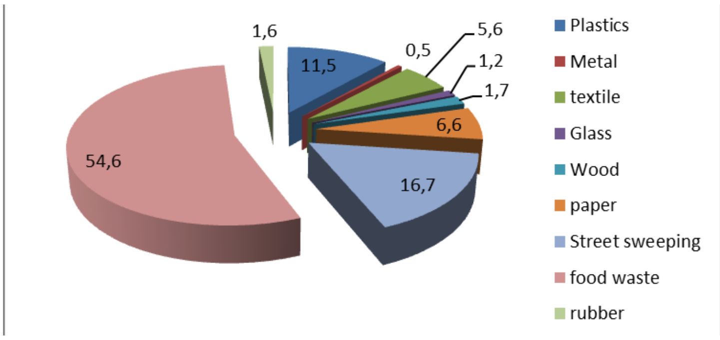

Fig. 1: Waste composition in Talangagung landfill

3.2. Waste Reduction

Scavenging activity is allowed in Talangagung landfill. There are 15 scavengers and they worked 6 days for an-organic waste sorting. Waste separated by scavengers is plastic, rubber, paper, cardboard, and glass (Fig. 2). Waste that can be reduced by scavenging activity is 1.36 percent of total volume comprising of plastic, paper, glass, cardboard and rubber for about 37.54 percent, 36.6 percent, 20.44 percent, 1.50 percent and 3.92 percent respectively. Based on the calculation, Talalangung landfill receives 18,775.6 million kg or 18,775.6 tons waste per year in 2014. This mass will be the baseline for waste projection calculation transported to Talangagung landfill from 2009 to 2028. It is assumed that Talangagung landfill will be operated for 20 years. Period of 20 years was chosen as the average minimum age of the landfill is considered worthy for at least 20 years old.

Total methane that can be produced for 20 years is 16,466.23 tons of CH_4 or 345,790.92 tons of CO_{2e}. Total production of methane gas from 2009 to 2014 was 2,206.85 tons of CH_4. Meanwhile, methane which is collected and distributed to 165 households (HHs) are amounting to 25,470 kg which means that only about 1.16 percent of potential methane gas is used. The rest is still stuck in a pile of waste and some have flowed into the air in the form of greenhouse gas (GHG) emissions. This is due to the final closure system of non-active cells in Talangagung landfill which is not ideal so that some of the waste is still visible.

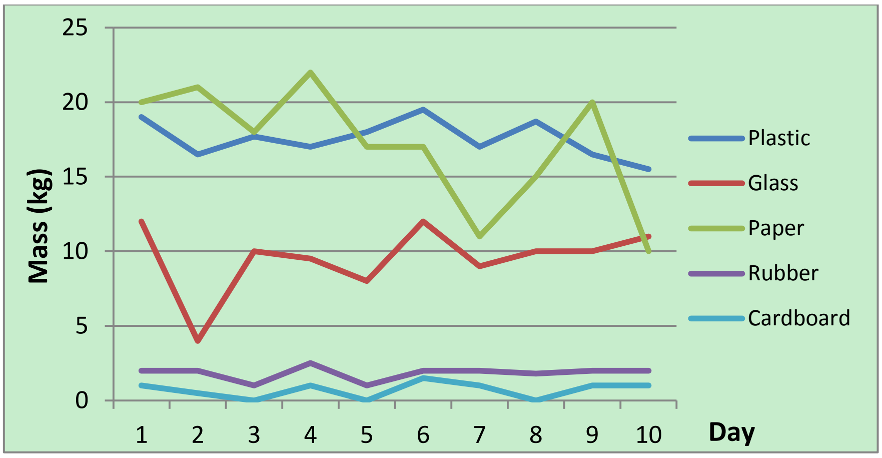

Fig. 2: Waste reduction by scavenger

3.3. Methane Generation

Fig.3 describes the methane generation from Talangagung landfill. By the end of 2027, total methane production is 16.466,23 ton CH4 or 345,790.92 ton $CO_{2e.}$ Methane distributed to the community (165 HHs) is 25.470 kg which is equal to 1.16 percent utilization rate

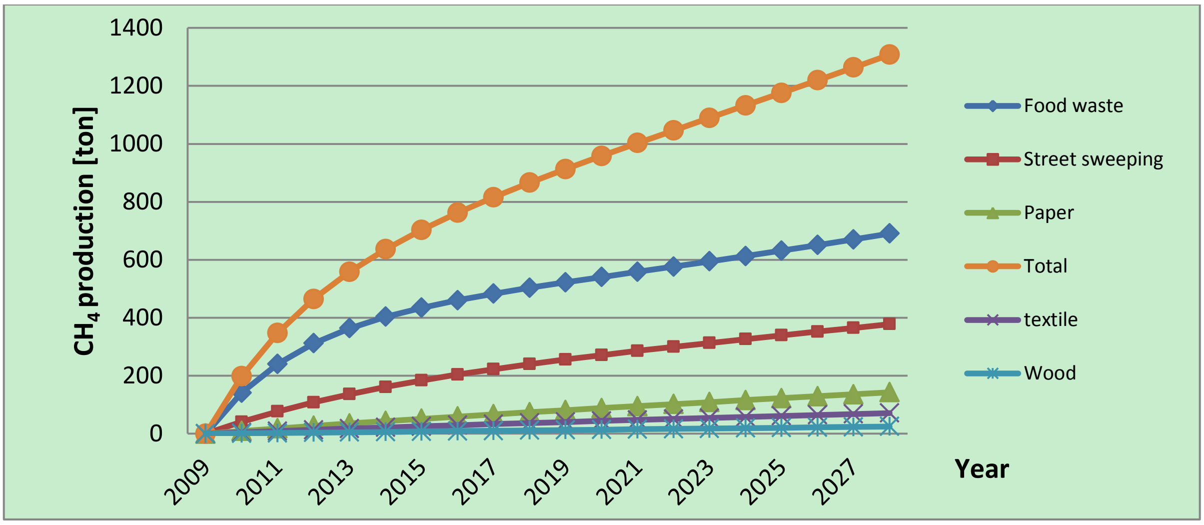

Fig. 3: Methane generation from Talangagung landfill

3.4. Emergy Calculation

Mixed waste input is assumed not to have emergy value because mixed waste is a product which is undesirable by humans and even produce undesirable emissions such as CO_2, CH_4 and other pollutants [14]. Waste material which is just dumped into landfill without any further process does not assigned for emergy and having transformity. In the contrary, if the waste is treated and contribute the next step of production process, it should be assigned to recycled material and calculated for its emergy. Therefore, biogas generated in Talangagung landfill is assummed as a product having transformity because it re-enters the next process which is end-use in form of heat for cooking in household.

Renewable resources include natural product obtained either free of charge or with the purchase, while the non-renewable primary purchased includes all the products that must be purchased to be included in the emergy system. Emergy costs are all components necessary inputs while emergy benefit is the flow of money coming from the sale of biogas and revenue scavengers. Conversion of value for money to unit emergy (seJ) using the factor of time is called emergy to money ratio in Indonesia which is 2.06E + 13 seJ/ $ [18].

Making of table emergy is the next stage after delineation and diagraming system of emergy system (Fig. 4). Large emergy calculations required for each type of input and emergy generated can be seen in Table 1. Transformity used in the study is taken from some references.

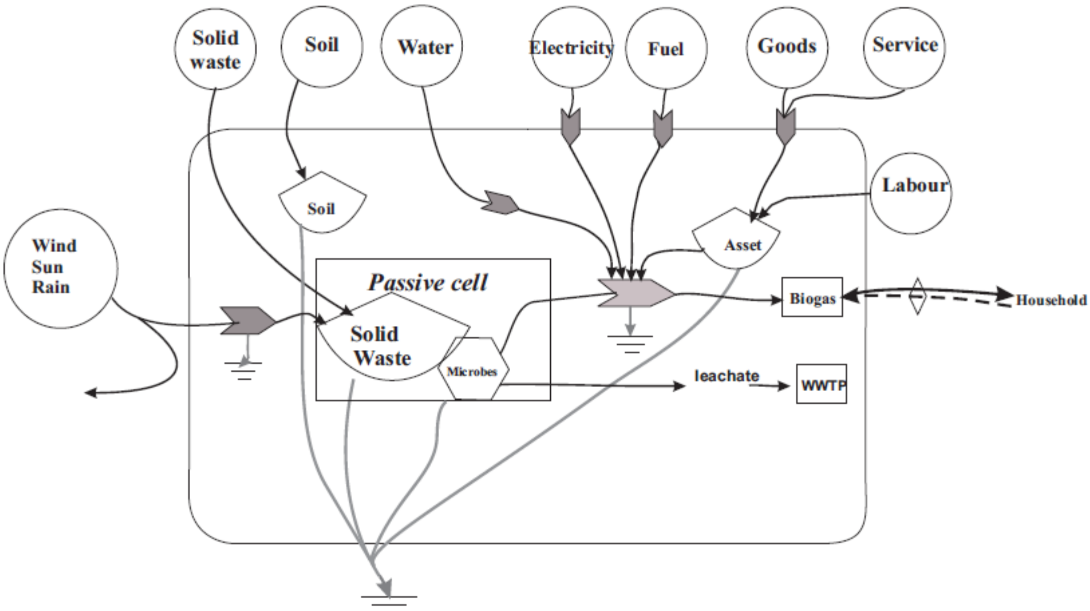

Fig. 4: Emergy system diagram

Table 1: Input and output of emergy in Talangagung landfill

No	Item	Unit	Amount	Transformity [seJ/unit]	Reference	Solar emergy [seJ/year]
Free Renewable Resource (RR)						
1	Scavenger	J	1.42E+11	4.63E+06	Meidiana, 2011[a,b] [19,20]	**6.57E+17**
Purchased Renewable Resource (RP)						
2	Water	g	1.10E+10	6.64E+05	Wang et. al.,2006 [21]	**7.27E+15**
Free Non Renewable Resource (NR)						
3	Material penutup (tanah)	g	1.04E+12	1.68E+09	Odum,1996 [6]	**1.74E+21**
Purchased Non Renewable Resource (NP)						
4	Soil for initial construction	g	3.08E+10	4.13E+09	Buranakarn,1998 [10]	1.27E+20
5	Fuel	J	1.35E+12	6.60E+04	Odum,1996 [6]	1.50E+17
6	Electricity	J	4.33,E+10	1.60E+05	Odum,1996 [6]	6.94,E+15
7	Vehicle	J	1.33E+11	7.76E+09	Odum,1996 [6]	1.03E+21
8	Labour	J	6.31E+09	4.63E+06	Meidiana,2012[a,b] [22,23]	2.92E+16
						1.16E+21
Economic services (NP)						
9	Initial construction cost	$	5.62E+05	2.06E+13	Univ. Florida,2000 [18]	1.16E+19
10	Operation and Maintenance	$	2.92E+05	2.06E+13	Univ. Florida, 2000 [18]	6.01E+18
11	Biogas collection system	$	9.92E+03	2.06E+13	Univ. Florida, 2000 [18]	2.04E+17
						1.78E+19
	Total average mass of waste per year	g	1.88E+10			
	Output					
	Total main LFG (CO_2, CH_4)	**g CO2e**	4.63E+10			
	Total solar emergy (1-11)	seJ/th				**2.92E+21**
	Transformity biogas	**seJ/J**		**5.12E+06**		

4. Conclusion

Scavenging activity in Talangagung Landfill has reduced 1.36 percent of total waste amount in landfill comprising of plastic, paper, glass, cardboard and rubber for about 37.54 percent, 36.6 percent, 20.44 percent, 1.50 percent and 3.92 percent respectively. The total methane generation is 16,466.23 ton CH_4 or 345,790.92 ton CO_{2e} from 2009 until 2028. 1.16 percent of the total biogas production is contributed to 165 households for cooking. The total emergy requiring for solid waste management in landfill is 2.92E+21 seJ and the transformity of the landfill biogas is 5.12E+06 seJ/J.

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