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DEVELOPMENT OF 3R WASTE TREATMENT FACILITIES FOR MITIGATING GREENHOUSE GAS EMISSIONS: A CASE STUDY OF PADANG CITY, INDONESIA

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ABSTRACT

This paper focuses on developing the role of people participation through solid waste banks (SWB) and 3R waste treatment facilities (TPS 3R) for mitigating global warming in Padang City. Current municipal solid waste (MSW) management and 3 improved scenarios were simulated for the next 20 years to calculate the impact on global warming. Greenhouse gases (GHG) inventory of waste treatment activities was carried out using LCA methodology. Meanwhile, methane emission from solid waste decomposition at landfill was calculated using IPCC software. Current MSW management practices show the achievement of waste recycling rate was only 2.178 % of total waste generation in 2015. Simulation results also show that implementing the current practice will release GHG emissions of 123.54 Gg CO_2eq in 2035. Improved scenario #3 suggests to increase the number of SWB, TPS 3R, integrated waste treatment facilities (TPST) and to install methane gas recovery. This improvement increases the recycling rate to around 34 % and reduces GHG emissions by around 57 %.

Keywords: 3R waste treatment facility, solid waste bank, global warming, greenhouse gases, MSW management.

INTRODUCTION

Naturally, atmosphere regulates earth's temperature at normal level, maintaining it warm enough for living organism. Greenhouse gases (GHG) has a vital function to creating such condition. However, over the last two centuries, anthropogenic activities have been increasing, which result in the larger emission of GHG (CO_2, CH_4, N_2O, HFCs, SF_4,). The increased concentration of GHG would force global climate change. It may trigger rises in sea level and atmospheric storm, changes in wind, rainfall and hydrological cycle, etc. Indonesia is very vulnerable to impact of climate change due to the condition and geographic position [1].

Among the five key sources, waste ranked the third biggest emission contributor to GHG emissions that accounted 11 %. IPCC methodology considers Solid Waste Disposal Sites (SWDS) for GHG emissions in municipal solid waste (MSW) sector. It produces significant amount of methane (CH_4) and biogenic carbon dioxide (CO_2). While CH_4 is emitted in smaller amount, its global warming potential (GWP) is 21 - 25 greater than that of CO_2 for 100-year time horizon [2]. Meanwhile, Most of Indonesian cities send their mixed MSW to SWDS without adequate recycling activities. Therefore, SWDS in Indonesia becomes the major contributor for CH_4 emission. Its potential for dispersion is significant considering the gas formation would last up to 30 years after the closure of landfill [3].

National action plan for waste sector sets to reduce GHG emissions of 48,000 Gg CO_2eq and 78,000 Gg CO_2eq for 26% and 41% target plan by 2020, respectively, through the implementation of integrated and 3R-based Municipal Solid Waste Management [4, 5]. The government has launched some national regulations targeting on increasing people awareness and participation in reduce, reuse and recycle activities. The Ministry of Environment has introduced solid waste bank (SWB) system as a social engineering tool for applying 3R concept among communities. SWB is still being improved and is expected to develop a collective awareness in waste recycling among people in Indonesia [6]. SWB is a unique social system operated by the communities in their daily life. It is a place for separating and collecting dry recyclable waste that has economic value. The community deposits the wastes instead of money. Even SWB adopts a banking system, it is a non-profit organization [7]. 3R waste treatment facility (*TPS 3R*) is another community-based system introduced by the government for treating compostable waste at source scale (group of 200-2,000 households) [8]. Raharjo, *et al*. suggested that the recycling activity must be carried out not only at source scale but also at municipality scale [6]. Ministry of Public Works issued a regulation about integrated waste treatment facility (*TPST*) at municipality scale. TPST treats dry marketable and compostable waste [9]. However, current data shows that the practice of such system is still very limited.

Padang is the capital city of West Sumatera Province. Padang has a population of around 854,336 people in 2015 with 11 districts and 104 villages. In 2013, Padang has a total waste generation of around 598,966 kg/day with 60 % was transferred to Air Dingin SWDS. However, recycling activities only accounted for 5 % (including total scavenger activities) of the total waste generation in 2013. Therefore, the rest of around 35 % would be disposed illegally to environment [6]. Air Dingin SDWS was operated as sanitary landfill, but the mixed waste entering the landfill would produce significant GHG.

Based on above description, it is important to study the contribution of community-based waste recycling improvement on GHG reduction from waste

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sector. This work will provide detail improvement of SWB, TPS 3R and TPST required for reducing GHG emissions in Padang City, which can be the guidance for other cities in Indonesia.

METHODOLOGY

Data were collected from agency of city cleaning and city environmental bureau, SWB, TPS 3R and TPST. Waste generation and composition, current practices of local MSW management, electricity and fuel usage for recycling activities, waste transportation system, daily activities at SWDS, etc. were collected for analysis. Currently, there are 47 SWBs in Padang. 5 SWBs from 3 communities, 1 university and 1 school were chosen for deep observation and interviews. Observation and interview were also carried out to investigate 4 TPS 3Rsincluding TPS 3R DarulUlum, TPS 3R Koto Lalang, TPS 3R Kami Saiyo, and TPS 3R KSM JatiBergema, and 2 TPSTs including TPST DKP and TPST TPA Air Dingin. Current MSW management (C) and 3 improved scenarios were simulated for the next 20 years (2016-2035) to study the benefit of developing community-based recycling system in mitigating global warming in Padang City. Improved scenarios were developed by increasing the recycling rate (%), which is assumed based on the local condition capabilities. Projection of population and waste generation for the next 20 years was also carried out to provide the basic data for the simulations. All material flows and activities associated with MSW treatment were analyzed and simulated to determine and understand their global warming potential (GWP) using LCA and IPCC methodology.

Greenhouse gases (GHG) inventory of waste treatment relating activities before landfill and at landfill site was carried out using life cycle assessment (LCA). Some activities associated with MSW treatment and GHG emissions comprise liquid fuel and electricity consumption for waste transportation, crushing and composting at SWB, TPS 3R and TPST. Boundary system of the study is displayed in Figure-1.

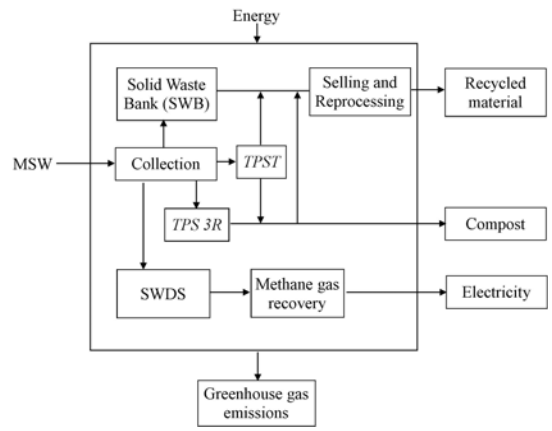

Figure-1. Boundary system of the study.

Meanwhile, methane emission from solid waste decomposition at landfill cells was calculated using Intergovernmental Panel on Climate Change (IPCC) software. GHG emissions for specific activities were calculated based on their emission factors as listed in Table-1.

Table-1. Emission factors used in this study.

Field	Emission factors
Electricity [10]	0,684693977 kgCO_2/kWh
Transportation [11]	motorcycle: 3180 g CO_2/kg fuel *Pick up*: 3178 g CO_2/kg fuel Truck: 3172 g CO_2/kg fuel
Composting [2]	CH_4: 4 (0,03-8) g CH_4/kg waste (wet basis) N_2O: 0,3 (0,06-0,6) g N_2O/kg fuel (wet basis)
Heavy vehicle [2]	CO_2: 74100 kg/TJ CH_4:4,15 kg/TJ N_2O: 28,6 kg/TJ
Liquid fuel for waste treatment [2]	Assume similar to manufacture industry CO_2: 74100 kg/TJ CH_4: 3 kg/TJ N_2O: 0,6 kg/TJ
Recovery landfill gas [12]	Specific gravity CH_4: 0,716 kg/m^3 Electric usage for landfill gas collection : 0,15 kWh/m^3 gas

GHG emissions must be expressed in CO_2eq using global warming potential (GWP) ratio as expressed in equation (1).

$$\text{Mass of } CO_2\text{eq} = (\text{mass of gas}) \times (\text{GWP}) \quad (1)$$

Based on IPCC Fourth Assessment Report 2007, GWP of CO_2, CH_4 and N_2O are 1, 21 and 310, respectively.

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RESULTS AND DISCUSSIONS

Projection of total waste generation

Padang has a waste generation of 0.67 kg/cap/day. Existing data of total waste generation (1986-2015) and its projection (2016-2035) are displayed in Table-2.

Current MSW management and improved scenarios

Observation on current MSW management practices show that around 75% of MSW are transported to Air Dingin SWDS. Small quantity goes to *TPST* DKP and *TPST* Air Dingin. Meanwhile, Table-3 shows recycling activities by communities in SWB and *TPS 3R* are still limited, account for only 0.812 % and 0 % in 2015, respectively. Figure-2 shows the current MSW management. Simulation of the current management assumes there was no improvement of recycling rate for the next 20 years as displayed in Table-3. It suggests that total recycling rate of the current MSW management are still limited, account for only 2.178 % in 2015. Implementing the current practices result in much lower total recycling rate to just around 1.494 % of the total waste generation in 2035.

Table-2. Total waste generation.

Year	Population	Total waste generation (ton/day)
1986	544,476	364.799
1990	591,704	396.442
1995	649,637	435.257
2000	713,242	477.872
2005	801,344	536.900
2010	833,562	558.487
2015	877,128	587.676
2020	888,851	595.530
2025	897,359	601.230
2030	904,041	605.707
2035	909,544	609.394

Figure-3 displays the improved scenario #1 (S1) of local MSW management. It is an improvement scenario of the current MSW management in which the recycling rate is gradually improved. Table-3 shows the improvement of recycling rate. Recycling rate of SWB, TPS 3R, and TPST is increased to 9.182%, 11.434%, and 11.159%, respectively. It is followed by the increased numbers of SWB,TPS 3R, and TPST DKP as listed in Table-4.Improved scenario #2 (S2) shows the addition of landfill gas recovery system onto the current MSW management as displayed in Figure-4. There is no improvement of recycling rate in scenario #2. As a development of scenario #1, scenario #3 (S3) is created. It simulates a MSW management in which improvement of recycling rate and installation of landfill gas recovery system are applied as illustrated in Figure-5. Landfill gas recovery efficiency is assumed increased gradually to 50% in 2035. Table-3 also displays the reduced waste transfer to SWDS due to the increased recycling rate. In this simulation condition, scavenger activities were not developed. Scavengers are expected to support the SWB, TPS 3R and TPST activities.

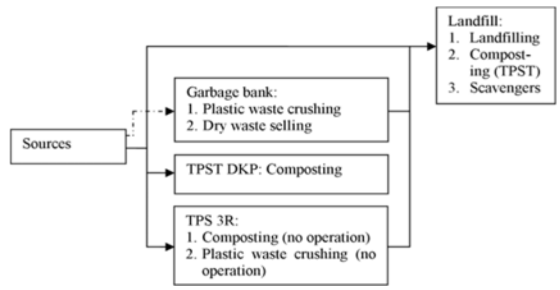

Figure-2. Current MSW management practices.

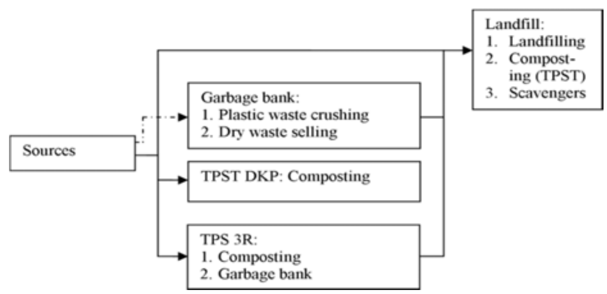

Figure-3. Improved scenario #1.

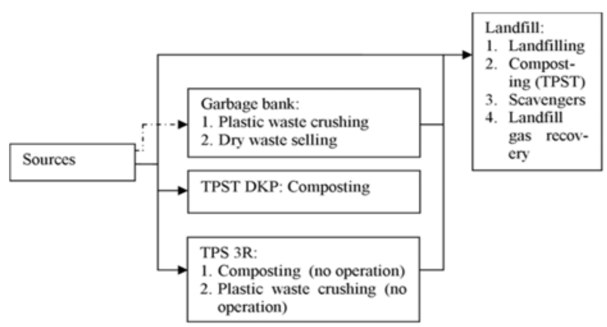

Figure-4. Improved scenario #2.

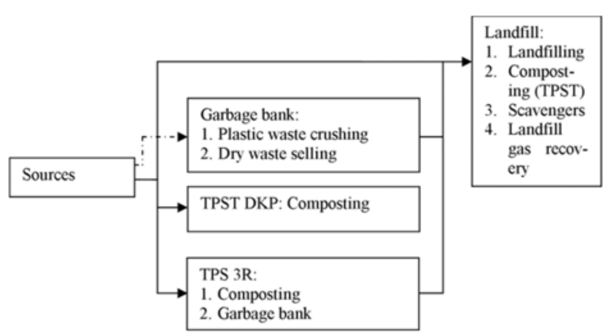

Figure-5. Improved scenario #3.

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Table-3. Condition and improvement of each simulation set up.

	Current	Scenario #1	Scenario #2	Scenario #3
Waste transferred to SWDS	No recycling improvement 74.73% (2015), 79.74% (2035)	With recycling improvement 74.73% (2015), 47.57% (2035)	No recycling improvement 74.73% (2015), 79.74% (2035)	With recycling improvement 74.73% (2015), 47.57% (2035)
Recycling rate before SWDS	a. SWB:0.812% (2015), 0.176% (2035) b. *TPS 3R*: 0% (2015), 0% (2035) *TPST* DKP:0.005% (2015), 0.005% (2035)	a. SWB: 0.182% (2015), 9.182% (2035) b. *TPS 3R*: 0% (2015), 11.434% (2035) c. *TPST* DKP: 0.005% (2015), 11.159% (2035)	a. SWB: 0.812% (2015), 0.176% (2035) b. *TPS 3R*: 0% (2015), 0% (2035) c. *TPST* DKP: 0.005% (2015), 0.005% (2035)	a. SWB: 0.182% (2015), 9.182% (2035) b. TPS 3R: 0% (2015), 11.434% (2035) c. *TPST* DKP: 0.005% (2015), 11.159% (2035)
Recycling rate at SWDS	a. *TPST* TPA: 0.085% (2015), 0.082% (2035) b. Scavengers: 1.276% (2015), 1.231% (2035)	a. TPST TPA: 0.085% (2015),0.656% (2035) b. Scavengers: 1.276% (2015), 1.231% (2035)	a. TPST TPA: 0.085% (2015), 0.082% (2035) b. Scavengers 1.276% (2015), 1.231% (2035)	a. TPST TPA: 0.085% (2015),0.656% (2035) b. Scavengers: 1.276% (2015), 1.231% (2035)
Landfill gas recovery	No landfill gas recovery	No landfill gas recovery	Landfill gas recovery with collection efficiency 2.5% (2015), 50% (2035)	Landfill gas recovery with collection efficiency 2.5% (2015), 50% (2035)

Raharjo, *et al.* suggested that Padang City should establish 3-4 unit of solid waste bank in every village for the next 20 years [6]. In 2035, there would be around 400 solid waste banks in which every solid waste bank may recycle around 140 kg/day of waste. As for the development of *TPS 3R*, it is expected that every village operates 1 unit which serves for around 200 households [13]. The increased numbers of SWB, *TPS 3R* and *TPST* are listed in Table-4.

Table-4. The increased number of recycling facilities.

	Current	Scenario #1	Scenario #2	Scenario #3
Solid waste bank	47 units (2015), 47 units (2035)	47 units (2015), 400 units (2035)	47 units (2015), 47 units (2035)	47 units (2015), 400 units (2035)
TPS 3R	4 units (2015) 4 Units (2035)	4 units (2015), 104 units (2035)	4 units (2015) 4 Units (2035)	4 unit (2015), 104 units (2035)
TPST	**a.** TPST DKP: 1 unit (2015), 1 unit (2035) **b.** TPST TPA: 1 unit (2015), 1 unit (2035)	**a.** TPST DKP: 1 unit (2015), 18 units (2035) **b.** TPST TPA: 1 unit (2015), 1 unit (2035)	**c**. TPST DKP: 1 unit (2015), 1 unit (2035) **d.** TPST TPA: 1 unit (2015), 1 unit (2035)	**c.** TPST DKP: 1 unit (2015), 18 units (2035) **d.** TPST TPA: 1 unit (2015), 1 unit (2035)

Comparison of GHG emissions

Figure-6 suggests that scenario #3 - with the improvement of SWB, TPS 3R, TPST and landfill gas recovery - results in the lowest GHG emissions. However, the increased recycling activity of around 34 % in scenario #1 reduces GHG emissions by around 22 % in time frame of 20 years in 2035 as displayed in Table-5. It is expected that applying recycling activities through the implementation of SWB, TPS 3R, TPST for longer time would give significant reduction of GHG emissions due to the reduced amount of waste transferred to landfill, therefore, minimizing methane emissions. Scenario #2 suggests that 50 % landfill gas recovery would reduce GHG emissions by 49 % in 2035. Applying recycling activities coupled with landfill gas recovery in scenario #3 reduces GHG emissions by around 57 %.

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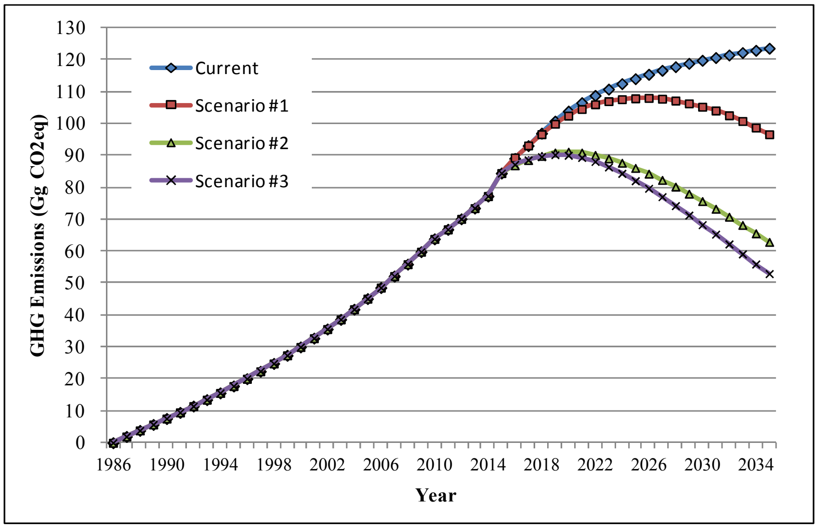

Figure-6. Comparison of GHG emissions of the four simulations.

Table-5. Reduced GHG emissions.

Strategy	**GHG emissions** ($Gg\ CO_2eq$)	**Reduced GHG emissions** ($Gg\ CO_2eq$)		
	2035	**C vs S1**	**C vs S2**	**C vs S3**
Current(C)	123,540			
Scenario #1 (S1)	96,594	26,946(21,811%)		
Scenario #2 (S2)	62,889		60,651 (49,094%)	
Scenario #3 (S3)	52,972			70,569 (57,122%)

C: Current MSW management
S1: Improved scenario #1
S2: Improved scenario #2
S3: Improved scenario #3

Proposed improved scenario for Padang city

Local action plan - GHG (*RAD - GRK*) 2004 issued by State Ministry of Development Planning (*Bappenas*) explains that West Sumatera Province is expected to reduce GHG emissions to around 275 Gg CO_2eq [14]. Applying scenario #3 in the local MSW management would give significant contribution from waste sector to the local action plan, which is around 26 %. Scenario #3 may be applied for local MSW management due to some reasons:

- Reduce significant GHG emissions.
- The local government has a program to reduce the waste generation by 20 % in 2030.
- The local government has a plan to install landfill gas recovery by 2017.
- The local government has a commitment to improve supervision on people participation in waste separation and recycling.

However, as suggested by Raharjo, *et al.* that the improvement of recycling activities through solid waste bank and *TPS 3R* requires coordination among the local government agencies [6]. SWB and *TPS 3R* must be formally well integrated with the daily local MSW management.

CONCLUSIONS

Current MSW management practices show that recycling rate are still limited, account for only 2.178 % in 2015. Current practices without improvement result in much lower recycling rate to just around 1.494 % of the total waste generation in 2035. Applying improved scenario #1 with the operation of recycling activities only reduces GHG emissions by 22 % in time frame of 20 years. Meanwhile, applying recycling activities coupled with landfill gas recovery in improved scenario #3 reduces GHG emissions by around 57 %. Scenario #3 may be applied due to the readiness of the local government. However, the improvement of recycling activities through SWB and TPS 3R requires coordination among the local government agencies [6]. SWB and TPS 3R must be formally well integrated with the routine local MSW management.

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