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Development of Community-Based Waste Recycling (garbage bank and 3R waste treatment facility) for Mitigating Greenhouse Gas Emissions in Padang City, INDONESIA

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***Abstract*— Observations and interviews on current municipal solid waste management (MSWM) in Padang City show the conventional operation of mixed collection, transportation and dumping to Air Dingin Landfill with limited recycling activities. Simulations result shows that practices of current local MSWM would release greenhouse gases (GHG) emissions of 123.54 Gg CO_2eq in 2035 after 50 years operation of the landfill. This paper focuses on developing scenarios of community-based recycling system for mitigating greenhouse gas emissions in Padang City. Observations and interviews to MSWM facilities and stakeholders were carried out to understand current condition of the local MSWM. 3 scenarios of improved recycling system were proposed based on the real condition and achievement of the current MSWM practice. Current MSWM practice and 3 improvement scenarios were simulated for the next 20 years (2016 – 2035) to understand the impact to global warming. GHG inventories of waste treatment activities before landfill and at landfill site was carried out using life cycle assessment (LCA). Meanwhile, methane emission from solid waste decomposition at landfill cells was simulated using Intergovernmental Panel for Climate Change (IPCC) software. As a result, current MSWM practice shows recycling achievement of only 1.494% of the total waste generation in 2035. Scenario #3 suggests to increase the number of garbage bank, community waste treatment facility (*TPS 3R*), integrated waste treatment facility (*TPST*) and to install landfill gas recovery. This improvement results in the higher recycling achievement of 33.66 % and lower GHG emissions of around 96.594 Gg CO_2eq compared to that of the current MSWM practice in 2035. While, the application of landfill gas recovery would further decrease the GHG emissions to 52.972 Gg CO_2eq. Scenario #3 may be applied for Padang City.**

***Keywords*— Garbage bank, 3R waste treatment facility, MSW management, global warming, greenhouse gases, mitigation strategy**

I. Introduction

Over the last two centuries, anthropogenic activities have been increasing. The increased fossil fuel utilization for transportation, industrial manufacture, forest clearance and waste generation results in the larger emission of greenhouse gases. CO_2, CH_4 and N_2O are known as the major GHGs. The global average concentration of CO_2 in the atmosphere has increased to 381 ppm from 280 ppm in 1750. It is the highest over the last 650,000 years [1, 2]. The increased concentration of GHGs in the atmosphere 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. Currently, Indonesia is among the world's 10 largest emitters of GHGs [3].

Indonesia declared a commitment on G-20 (Pittsburgh) and COP15 (Copenhagen) to reduce 26 % and 41 % GHG emissions by 2020 using self-efforts and international assistance, respectively [4]. Among the five key sources of forest and peat, energy and transportation, waste, industry and agriculture, waste ranked the third biggest emission contributor that accounted 11 %. IPCC methodology considers Solid Waste Disposal Sites (SWDS) for GHG emissions in 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 [5]. Most of Indonesian cities send their mixed MSW to landfill without separation and adequate recycling activity. Therefore, landfill in Indonesia becomes the major contributor for CH_4 emission. National action plan for waste sector sets to reduce GHG emissions for 26% and 41% target plan by 2020 using self-efforts and international assistance, respectively, through the implementation of integrated and 3R-based Municipal Solid Waste Management [6, 7]. The action plan is supported

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by the issuance of a regulation *PermenLH* No. 13/2012, which rules the guidelines on reduce, reuse and recycle through garbage bank [8]. The Ministry of Environment has introduced garbage bank system as a social engineering tool for applying 3R concept among communities. Garbage bank is still being improved and is expected to develop a collective awareness in waste recycling among people in Indonesia [8]. 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) [9]. Raharjo, et al. suggested that the recycling activity must be carried out not only at source scale but also at municipality scale [8]. Ministry of Public Works issued a regulation about integrated waste treatment facility (*TPST*) at municipality scale. TPST treats dry marketable and compostable waste [10].

Weitz et al. studied the track changes of GHG emissions during the last 25 years from the management of MSW in United States. They estimated that the increased recycling, composting, combustion (with energy recovery) and landfilling with gas recovery, control and utilization have significantly reduced the potential GHG emissions from ~60 million metric tons carbon equivalents (MMTCE) to 8 MMTCE in 1997 despite an almost 2-fold increase in waste generation [11]. Pan et al. suggested that organic material and potentially reusable or recyclable material (paper, card, green waste, and other putrescibles from MSW) must be reduced, sorted and treated before landfilling. GasSim simulation showed that reductions in methane production of 74% could be achieved if a 90% organic content can be reduced during biological treatment on mechanically sorted organic residues (MSORs) [12].

Padang is the capital city of West Sumatera Province. Padang has a population of around 877,128 people in 2015 with 11 districts and 104 villages. In 2013, Padang has a total waste generation of around 587.68 ton/day with 60 % was transferred to Air Dingin Landfill. However, recycling activities only accounted for 3 % of the total waste generation in 2013. Therefore, the rest of around 35 % would be disposed illegally to environment [8]. Air Dingin Landfill was operated as sanitary landfill, but the mixed waste entering the landfill would produce significant GHG. As for recycling activities, Padang has garbage banks, *TPS 3Rs* and *TPSTs*. However, current data shows that the practice of such systems is still very limited. Based on above description, it is important to study the development of community-based waste recycling and its contribution to GHG reduction from waste sector. This work will provide detail improvement of garbage bank, *TPS 3R* and *TPST* required for reducing GHG emissions in Padang City.

II. Methodology

Secondary data including waste generation and composition and current practices of local MSWM was collected from Agency of Padang City Cleaning and Padang City Environmental Bureau, garbage banks, *TPS 3Rs* and *TPSTs*. Meanwhile, primary data was obtained from field observation and interviews to stakeholders. Field observations and interviews were carried out on garbage banks, *TPS 3Rs* and *TPSTs*. Currently, there are 47 garbage banks in Padang. 5 garbage banks comprise of 3 communities, 1 university and 1 school garbage banks were chosen for deep observation and interviews. Observation and interviews were also carried out to investigate 4 *TPS 3Rs* (*TPS 3R* Darul Ulum, *TPS 3R* Koto Lalang, *TPS 3R* Kami Saiyo, *and TPS 3R* KSM Jati Bergema), and 2 *TPSTs* (*TPST DKP* and *TPST TPA* Air Dingin).

Data processing and analysis comprise the projection of population and waste generation (19866 -2035), analysis on current local MSWM, prediction of GHG inventory of current and improved MSWM and analysis on appropriate scenario of local MSWM for Padang City. Apart from current local MSWM practice (no improvement), 3 scenarios were proposed as improvement steps of the current system. All material flows and activities associated with MSW treatment were analyzed and simulated to determine and understand their global warming potential (GWP). The simulations were carried out for the next 20 years (2016–2035), except for methane emissions from landfill, that must be simulated from the opening of landfill (1986–2035). GHGs inventory of waste treatment activities before landfill and at landfill site was carried out using life cycle assessment (LCA) methodology. The activities comprise liquid fuel and electricity consumption for waste transportation, crushing and composting, and electricity for methane recovery. Meanwhile, methane emission from solid waste decomposition at landfill cells was calculated using Intergovernmental Panel for 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

	Faktor Emisi
Electricity [13]	0.68 kg CO_2/kWh
Transportation[15]	motorcycle: 3.18 kg CO_2/kg fuel *Pick up*: 3.18 kg CO_2/kg fuel Truck: 3.17 kg CO_2/kg fuel
Composting [14]	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 [14]	CO_2: 74,100 kg/TJ CH_4:4.15 kg/TJ N_2O: 28.6 kg/TJ
Liquid fuel for waste Treatment [14]	Assume similar to manufacture industry CO_2: 74,100 kg/TJ CH_4: 3 kg/TJ N_2O: 0.6 kg/TJ
Recovery landfill gas [16]	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 following 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.

III. Results and Discussion

A. Existing and 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.

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

B. Current MSWM practice and improved scenarios

Current MSW management practices show that most waste was transported to Air Dingin Landfill. Small quantity goes to *TPST DKP* and *TPST* Air Dingin. Meanwhile, as displayed in Table 3, recycling activities by communities in garbage bank and *TPS 3R* are still limited, account for only 0.182 % and 0 %, respectively, in 2015. The total recycling achievement is around 1.548 % in 2015, which is lower than the achievement in 2013 [8]. Figure 1 shows the current MSWM practice. Simulation of the current MSWM practice assumes there was no improvement for the next 20 years. Because of this, the recycling achievement would depress to only 0.176 % for garbage bank in 2035. The total recycling achievement would be around 1.494 % in 2035 as displayed in Table 3.

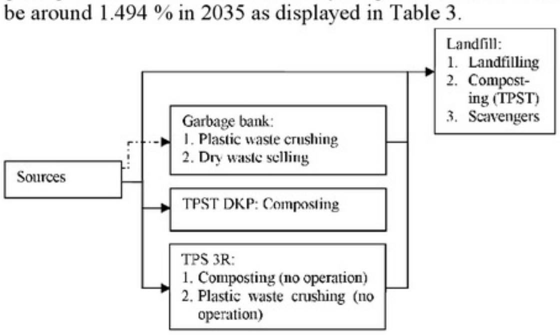

Figure 1 Current MSW management practice

Figure 2 displays the improved scenario #1 of local MSWM. The numbers of garbage bank, *TPS 3R* and *TPST* were set to increase for the simulation period. Table 3 shows that the total recycling achievement would increase from 1.548 % in 2015 to 33.662 % in 2035.

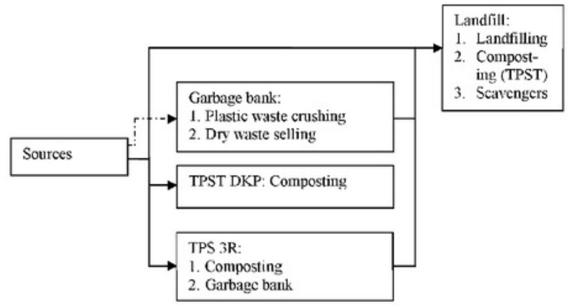

Figure 2 Improved scenario #1

Improved scenario #2 shows the addition of landfill gas recovery system onto current MSWM practice as displayed in Figure 3.

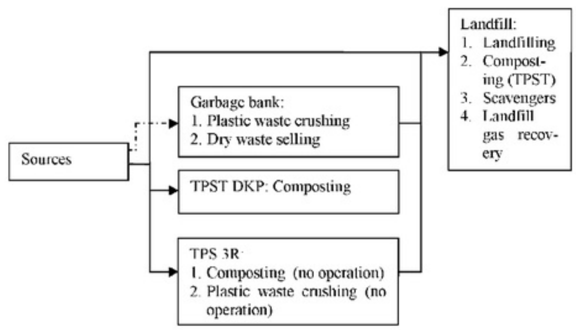

Figure 3 Improved scenario #2

As a development of scenario #1, landfill gas recovery system is installed at landfill site as displayed in Figure 4.

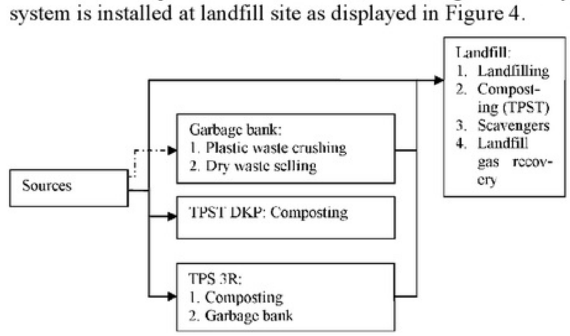

Figure 4 Improved scenario #3

Furthermore, Table 3 lists detail condition and improvement of the four simulation set up.

Table 3 condition and improvement of each simulation set up

	Current	Scenario #1	Scenario #2	Scenario #3
% Waste transferred to landfill	73.45% (2015), 78.51% (2035)	73.45% (2015), 46.51% (2035)	73.45% (2015), 78.51% (2035)	73.45% (2015), 49.14% (2035)
Recycling before landfill	a. Garbage bank: 0.182% (2015), 0.176% (2035) b. Composting at TPST DKP: 0.005% (2015), 0.005% (2035)	a. Garbage bank 0.182% (2015), 9.182% (2035) b. Recycling at TPS 3R: 0% (2015), 11.434% (2035) c. Composting at TPST DKP: 0.005% (2015), 11.159 % (2035)	a. Garbage bank: 0.182% (2015), 0.176% (2035) b. Composting at TPST DKP: 0.005% (2015), 0.005% (2035)	a. Garbage bank 0.182% (2015), 9.182% (2035) b. Recycling at TPS 3R: 0% (2015), 11.434% (2035) c. Composting at TPST DKP: 0.005% (2015), 11.159% (2035)
Recycling at landfill	a. Composting (TPST TPA): 0.085% (2015), 0.082% (2035) b. Scavenger: 1.276% (2015), 1.231% (2035)	a. Composting (TPST TPA): 0.085% (2015), 0.656% (2035) b. Scavengers: 1.276% (2015), 1.231% (2035)	a. Composting (TPST TPA): 0.085% (2015), 0.082% (2035) b. Scavengers 1.276% (2015), 1.231% (2035)	a. Composting (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 units of garbage bank in every village for the next 20 years [8]. In 2035, there would be around 400 garbage banks in which every garbage 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 [17]. The increased number of garbage bank, *TPS 3R* and *TPST* are listed in Table 4.

Table 4 The increased number of recycling facilities

	Current	Scenario #1	Scenario #2	Scenario #3
Garbage 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), 16 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), 16 units (2035) d. TPST TPA: 1 unit (2015), 1 unit (2035)

C. Comparison of GHG emissions

Figure 5 suggests that scenario #3 - with the improvement of garbage bank, *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 4. It is expected that applying recycling activities through the implementation of garbage bank, *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 integrated with landfill gas recovery in scenario #3 reduces GHG emissions by around 57 %.

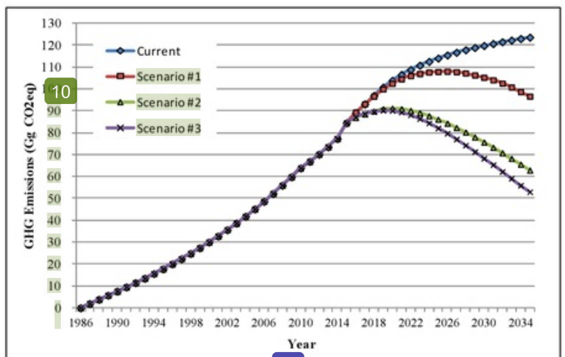

Figure 5 Comparison of GHG emissions of the four simulations

Table 4 Reduced GHG emissions

Strategy	GHG Emissions (Gg CO_2eq)	Avoided GHG Emissions (Gg CO_2eq)		
	2035	C vs S1	C vs S2	C vs S3
Current (C)	123.540			
Scenario #1 (S1)	96.594	26.95 (21.81%)		
Scenario #2 (S2)	62.889		60.65 (49.09%)	
Scenario #3 (S3)	52.972			70.57 (57.12%)

D. Proposed improved scenario for Padang City

Local action plan-GHG (*RAD – GRK*) 2004 issued by State Ministry of Development Planning explains that West Sumatera Province is expected to reduce GHG emissions by 275 Gg CO_2eq [15]. Applying scenario #3 in the local MSWM would give significant contribution from waste sector to the local action plan, which is around 26 % of avoided GHG emissions.

Scenario #3 may be applied for local MSW management due to some reasons:

1. Reduce significant GHG emissions.
2. The local government has had a program to reduce the waste generation by 20 % in 2030.
3. The local government has had a plan to install landfill gas recovery by 2017.
4. 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 garbage bank and *TPS 3R* requires coordination among the local government agencies [8]. Garbage bank and *TPS 3R* must be formally well integrated with the local MSWM practice.

IV. Conclusion

Current MSWM practice shows that recycling activities are still limited, account for only 2 % and 1.548 % in 2013 and 2015, respectively. Current practices without improvement result in even lower recycling activities to just around 1.494 % of the total waste generation in 2035.

Scenario #1 and #3 improved the recycling activities through garbage bank and TPS 3R. The recycling achievement is improved to a total of 34 % of the total waste generation in 2035. Meanwhile, scenario #3 is also equipped with landfill gas recovery system. Applying scenario #1 with the operation of recycling activities only would reduce GHG emissions by 22 % in time frame of 20 years. Meanwhile, applying recycling activities coupled with landfill gas recovery in scenario #3 reduces GHG emissions by around 57 % in just 20 years.

Scenario #3 may be applied due to the readiness of the local government. However, the improvement of recycling activities through garbage bank and *TPS 3R* requires coordination among the local government agencies [8]. Garbage bank and *TPS 3R* must be formally well integrated with the daily local MSWM.

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