

Research article

GWP, AP, and EP Contribution on Potential Improving Scenarios of Domestic SWM in Padang City: A Review

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Abstract

The increase in solid waste generation is incompatible with solid waste management (SWM). Padang city has a small processing percentage of 5% through composting and recycling. Improper and nonoptimal SWM leads to many obstacles, including climate change, water and soil contamination, to creatures life disturbance. By conducting Impact Assessment and Contribution Analysis, this study examines the most impact contributor of unit processes in four scenarios of domestic solid waste management in Padang City. Scenario 0 presents the existing condition; scenarios 1, 2, and 3 present the improvement of Scenario 0 in recycling percentage rate and technology implementation in a row by composting, incineration, and anaerobic digestion. CML2001, impact assessment method by the Center of Environmental Sciences of Leiden University, is used to assess the environmental impact of Global Warming Potential (GWP), Acidification Potential (AP), and Eutrophication Potential (EP). This study found that the significant impact for the four scenarios is GWP by the contribution percentage over 72%. While, EP is the second place in the contribution range of 1.70% to 5.46%, and followed by AP under 0.91%. Scenario 1 is the best scenario due to the small contribution of impact compared to other scenarios, and potentially to be applied by modification in increase of composting percentage and additional recovery gas in the landfill.

Keywords: Impact Contribution, Contribution Analysis, Solid Waste Management, LCIA

1. Introduction

Solid waste is an issue for many cities in Indonesia, including Padang City, due to the increase in solid waste generation and improper management. The increase in solid waste every year is related to the increasing number of people and their consumptive habits (Badan Pusat Statistik, 2016). Most domestic and non-domestic solid waste collected is unsorted from source (Aziz and Febriardy, 2016), and hence the difficulties in waste processing. It is only 5% of solid waste was composted and recycled in Padang City. 60% of solid waste generation has the end cycle in a landfill. The other 35% were open burned and thrown away by the community into the river (Raharjo *et al.*, 2017).

The practical of improper solid waste management (SWM), open dumping landfill and open burning, are the major source of greenhouse gases (GHG) in Indonesia. There was 42.76 megatonnes of solid waste approximately produced in Indonesia and lead to a significant amount of GHG equivalents, in particular methane emitted. Methane is 28 to 36 times more potential for climate change than carbon dioxide over a 100-year period (Badan Perencanaan Pembangunan Nasional, 2010). Hence, improper SWM is delivered the second biggest reason for climate change after the deforestation (Jatmiko, 2011).

Water contamination due to improper SWM potentially occurs in common at 8.5% of unmanaged waste in Indonesia (Kementerian Lingkungan Hidup dan Kehutanan, 2017). Case in Padang City shows solid waste streamed away by five big rivers to Padang Beach as the contamination due to community irresponsible for SWM (Candra and Aini, 2018). It will improve the marine litter in global, enhancing the wide environmental contamination (UNEP, 2009). The inadequate landfill (open dumping and uncontrolled landfill) potentially generates dangerous heavy metals pollution emitting in the water (Vongdala *et al.*, 2019). Inconsequent, improper SWM can cause the sever and various environmental impact and social impact, pursuing the obstacles of sustainable development improvements (Ferronato and Torretta, 2019).

In order to pursue the responsible and environmentally friendly SWM in Padang city, there are four scenarios of potential improvement have been suggested. The scenarios are based on existing improvement by technology addition and processing percentage. Additional technologies are including composting, anarobic digestion, incineration, and landfill gas recovery (Wulandari *et al.*, 2021). This study examines the three impact contributors of unit processes in four scenarios suggested through Impact Contribution Analysis. The analysis uses Life Cycle Impact Assessment (LCIA) method to describe the distribution of impact contribution to each process so that improvement suggested is consider based on the assessment results.

2. Material and Method

2.1 Scenario and Data Inventory

Domestic solid waste in Padang City is classified into organic (also known as wet waste) and inorganic waste (dry waste) (Hafizh, 2017). The term of wet waste is also mentioned as compostable waste, comprises food waste and yard waste. The dry waste is comprised recycleable waste including plastic, paper, metal, cardboard, glass, etc. Both of compostable and recycleable solid waste have combination of recycling potential about 65.16%. Compostable solid waste has a significant recycling potential of 59.86%, while recycleable solid waste relatively small of 5.3% (Hafizh, 2017).

This study assess four scenarios comprised existing scenario (Scenario 0) and improving scenario (Scenario 1 – 3). The improvement applied includes additional technology and increase the processing percentage. Table 1 describes the detail information of each scenario, while the Figure 1 shows the waste flow in general.

In existing condition (Scenario 1), solid waste is collected in mixed conditions, while the other scenarios applied three types of waste sorting including compostable, recycleable, and other/residue. The exist processing treat the compostable waste by 25% of composting at reduce reuse recycle waste processing station (3R WPS), and increase 1,4% in scenario 1. Scenario 2 uses incineration as additional tehcnology for processing compostable waste at 25,80%, while the scenario 3 uses additional anaerobic digestion at 1,4%. Recycling effort for the recycleable waste in temporary waste container (TWC) by the scavengers is relatively similar due to government capacity to engage the scavengers in sorting the recycleable waste. It is only 0.05% of recycleable waste stored to Waste Bank by the community, and it is assumed to increase 1,4% for all improvement scenario. The leftover waste goes to TWC and dispose to landfill. The scope of impact assessment analysis for this study limits by the boundaries of unmanaged waste, compostable waste processing, and lanfill. Moreover, recycleable waste processing wouldn't be assessed due to emission factor limited inventory data.

The functional unit used in input system of LCA Software is 1-ton waste. The additional inventory data (including the emission factors) is adopted from Gabi 5 Education as LCA Software, previous researches, and manual books (Sundqvist, 1999; Komilis and Ham, 2004; Mendes, Aramaki and Hanaki, 2004; McDougall *et al.*, 2007; Levis and Barlaz, 2013a, 2013b; Ahrens *et al.*, 2015).

Table 1. Improving scenarios of domestic SWM in Padang City^a

Waste Condition	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Mixed Waste	100.00%	-	-	-
Sorted Waste				
- Compostable Waste	-	68.86% ^d	68.86% ^d	68.86% ^d
- Recycleable	-	22.80% ^d	22.80% ^d	22.80% ^d
- Other Waste	-	8.34% ^d	8.34% ^d	8.34% ^d
Unmanaged Waste	35.00% ^b	25.00% ^e	25.00% ^e	25.00% ^e
Processing of Compostable Waste				
- Composting	2.00% ^b	3.40% ^{b+f}	2.00% ^b	2.00% ^b
- Anaerobic Digestion	-	-	-	1.40% ^f
- Incineration	-	-	25.80% ^g	-
Processing of Recycleable Waste				
- Recycling by Scavengers	3.00% ^b	3.00% ^b	3.00% ^b	3.00% ^b
- Recycling by Waste Bank	0.05% ^{bc}	1.40% ^f	1.40% ^f	1.40% ^f
Landfill				
- Without Landfill Gas Recovery	60.00% ^b	-	42.80% ^h	-
- With Landfill Gas Recovery	-	67.20% ^h	-	67.20% ^h

a (Wulandari, 2018), assumed in 2018 for implementation scenario in 2023

b (Raharjo et al., 2017)

c Due to very small percentage, it isn't involved in the waste reduction calculation during processing

d (Hafizh, 2017), Compostable waste: food waste and yard waste; Recycleable waste: paper, plastic, glass, and metal; Other waste: bulky wood, textile, rubber, leather, etc.

e (Kementerian Lingkungan Hidup dan Kehutanan, 2018a), waste reduction projection increase 2% per year, accumulation 2018-2023: 10%.

f (Kementerian Lingkungan Hidup dan Kehutanan, 2018b), assumed waste processing percentage increase 0.28% per year (twice higher than achievement in 2017 to 2018)

g Assumed that Incineration can process 50% of compostable waste due to local government budget constraints.

h Percentage of residue for disposing to landfill (the total of managed waste - the total of processing waste)

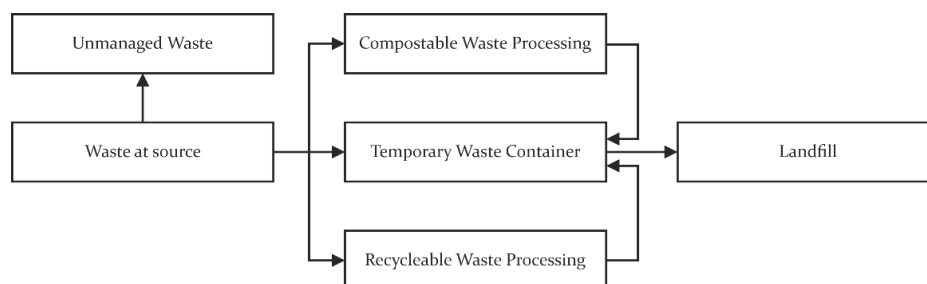


Figure 1. Flow diagram for all scenarios

2.2 Life Cycle Impact Assessment

Model of each scenario input to Gabi 5 Education Software, including data from **Table 1** and other inventory data. The impact category is selected from CML 2001 comprised GWP, AP, and EP. The three categories are chosen due to lot of previous studies discussed these impacts, and they had significant effects to the environment and humans. GWP analyzes contribution compounds of GHG, including CO₂ (Carbon dioxide) and CH₄ (Methane). It defines as kg CO₂ equivalent unit. AP analyzes contribution of acidification causes compounds, including SO_x, NO_x, HF, and HCl. AP defin as kg SO₂ equivalent unit. Moreover, EP analyzes contribution of eutrophication causes, including nitrogen and phosphor, and defines as kg PO₄³⁻ equivalent unit. These three impacts normalize and score to solve the inconsistency of inventory data available and assess affection for each impact on affection for all impacts. The normalization and scoring factors can be shown in **Table 2**.

Table 2. Normalization and scoring factors (PE International AG, 2012)

Impact Categories	Normalization Factor	Scoring Factor
CML2001 - Apr. 2015, AP	4,18E-12	6,1
CML2001 - Apr. 2015, EP	6,32E-12	6,6
CML2001 - Apr. 2015, GWP 100 years	2,39E-14	9,3

2.3 Impact Contribution

Contribution analysis is used to identify environmental loads that highly contribute to the total environment impact. Particularly, the results are displayed as percentages (Elcock, 2007). The identification of Life cycle stages, activities, processes, materials, or components, that have percentages greater than 1%, are classified as contributor that have the significant impact on the total impact. As the interpretation of LCA stages, the results used in this analysis can be characterized impact, weighted impact or inventory results (Lee and Inaba, 2004). This research uses weighted impact contribution analysis to define the most contributor of the processes.

3. Result and Discussion

This study found that the significant impact for the four scenarios is GWP by the contribution percentage over 72%. While EP is the second place in the contribution range of 1.70% to 5.46%, and followed by AP under 0.91% (see **Table 3**). Since the impact percentages greater than 1% classified as significant impact contributor (Lee and Inaba, 2004), GWP and EP are the significant contributor. Due to the significant impact contributor, it means GWP and EP potentially harm the environment and human life. However, AP still has slight impact by the minor damage.

Table 3. Contribution assessment result in point and percentage

Impact Category	GWP		AP		EP		Total	
Scenario 0								
- Unmanaged Waste	6.32E-10	35.88%	9.16E-13	0.05%	1.09E-11	0.62%	6.44E-10	36.55%
- Composting	4.62E-12	0.26%	6.72E-13	0.04%	1.79E-13	0.01%	5.47E-12	0.31%
- Landfill	1.09E-09	62.00%	1.58E-12	0.09%	1.88E-11	1.07%	1.11E-09	63.14%
Total	1.73E-09	98.12%	3.17E-12	0.18%	2.99E-11	1.70%	1.76E-09	100.00%
Scenario 1								
- Unmanaged Waste	4.52E-10	71.47%	6.56E-13	0.10%	7.78E-12	1.23%	4.60E-10	72.80%
- Composting	1.18E-12	0.10%	1.14E-12	0.18%	3.00E-13	0.05%	2.63E-12	0.42%
- Landfill with LFG	1.40E-10	1.23%	3.95E-12	0.62%	2.49E-11	3.93%	1.69E-10	26.78%
Total	5.93E-10	72.81%	5.75E-12	0.91%	3.30E-11	5.21%	6.32E-10	100.00%
Scenario 2								
- Unmanaged Waste	4.52E-10	67.28%	6.55E-13	0.10%	7.78E-12	1.16%	4.60E-10	68.68%
- Composting	4.62E-12	0.69%	6.72E-13	0.10%	1.77E-13	0.03%	5.47E-12	0.82%
- Incineration	5.47E-11	8.17%	2.83E-12	0.42%	9.19E-13	0.14%	5.85E-11	8.73%
- Landfill	1.32E-10	19.68%	3.06E-13	0.05%	1.38E-11	2.05%	1.46E-10	21.78%
Total	6.43E-10	95.96%	4.47E-12	0.67%	2.26E-11	3.38%	6.70E-10	100.00%
Scenario 3								
- Unmanaged Waste	4.52E-10	68.98%	6.55E-13	0.10%	7.78E-12	1.19%	4.60E-10	70.27%
- Composting	4.62E-12	0.71%	6.72E-13	0.10%	1.77E-13	0.03%	5.47E-12	0.83%
- Anaerobic Digestion	1.37E-15	0.00%	2.86E-18	0.00%	1.70E-13	0.00%	1.37E-11	0.00%
- Landfill with LFG	1.57E-10	23.97%	4.42E-12	0.67%	2.78E-11	4.25%	1.89E-10	28.90%
Total	6.13E-10	93.66%	5.75E-12	0.87%	3.58E-11	5.46%	6.55E-10	100.00%

The current popular issue is related to climate change and global warming. Uncontrolled landfill, and open burrying or open burning of unmanaged waste are the most activities that place solid waste management as the second largest contributor in climate change (Jatmiko, 2011). The GWP of unmanaged waste occurs in all potential scenarios, while the uncontrolled landfill only occurs in scenario 0 and scenario 2 due to the absence of landfill recovery gas facility. Table 3 and Figure 2 show the domination of these two stages for GWP contribution. Furthermore, compostable waste processing, including composting, incineration, and anaerobic digestion also contribute to GWP. This study found that incineration has the highest impact contibution compared to the two others. Besides, previous research (Hutton, Horan and Norrish, 2009) found the otherwise. Incineration has least impact compared to composting and landfill equipped with gas recovery facility, due to the reduction of GHG from compostable waste and the capture of emission for energy and electricity. The difference of assessment result can come from the period of GWP assessed, and stage percentage of the scenarios. Hutton et.,al. use 30 years period of GWP and assume the same percentage for the stages, while this study uses 100 years period and variation in processing stages. Moreover, anaerobic digestion with special waste sorting can produce best compost, and methane as the raw of energy for electricity 80 - 100 kWh per tonne of waste (Hutton, Horan and Norrish, 2009). Due to methane utilization, anaerobic digestion contributes in very small percentage impact, this study found under 0.001% of total impact contribution.

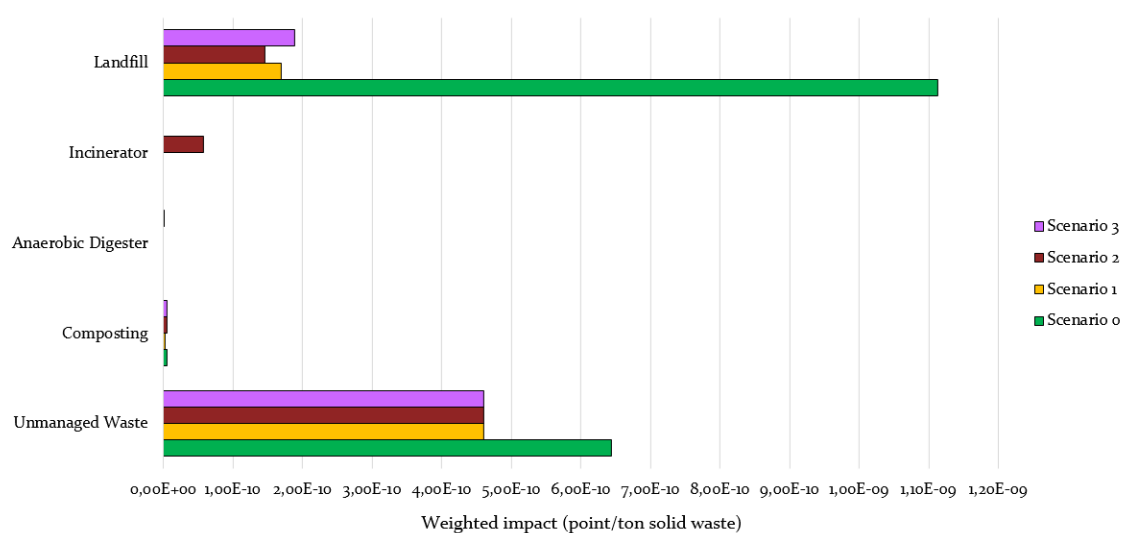


Figure 2. Weighted impact per life cycle stages (point/ton solid waste)

It is difficult to track the waste flow and how the community treat the unmanaged waste precisely. It closely has relationship to AP and EP when unmanage waste is thrown into rivers. The open burning issue led the incomplete combustion process, generates contaminants of GHG and improving human health risk (Tue *et al.*, 2016). Moreover, the uncontrolled landfill, including opendumping, potentially releases CH₄ that impact global warming 28 - 36 times more danger than CO₂. GWP as the cause of climate change can lead to some serious issue, including flooding, prolonged droughts, increase the extreme weather events frequency, and risk the biodiversity (Badan Perencanaan Pembangunan Nasional, 2010). The worsen conditions to avoid is the explosion of CH₄ which trapped in landfill pile that has happened at Leuwi Gajah Landfill in 2005. It causes 157 people died and village lossing due to landslide after pile explosion (Darmanto and Achmad, 2020). The use of landfill gas recovery facility will be useful to reduce GHG released and explosion opportunity.

In spite of the minor damage opportunity caused by AP, it is important to explain how it would be worse due to the absence of mitigation. Acidification is environmental issue that led rivers/stream

acid contamination and soil. It support the increase of mobilization and infiltration heavy metals in soil and worsen animal and plants condition by harming their food web (Kim and Chae, 2016). This study found that the highest AP contribution occurs in landfill stages for all scenarios and incineration for Scenario 2. The untreated leachate and acid gases from landfill can cause both ground and surface water contamination due to rainfalls (Naveen, Sumalatha and Malik, 2018; Nhubu and Muzenda, 2019), so does the unmanaged waste. Beside heavy metals, leachate contains high concentrations of organic compounds and other toxic contents that can cause any significant harmful to aquatic lives balance, environment, and human health as the contaminat flow to transfer in water, plants, and animal that consumed by human (Jaishankar *et al.*, 2014; Naveen, Sumalatha and Malik, 2018). Air acidifying happens due to gas emission of the Incineration stage. Several acid compounds will cause acid rain in the pH range of 4.2 to 4.4 (Hallback, 2017; Nunez, 2019). Acid rain lead the harm of creatures, including the malnutrision and dead of aquatics, animals, plants, and trees, also cause irritant and organ disturbance while contacted to human (United States Environmental Protection Agency, 2016). Futhermore, Composting and Anaerobic Digestion have a slight impact in AP contribution by NH₃ as the gases depositions that led smog formation, soil acidification, air quality reduction, and soil water eutrophication (Al-Rumaihi *et al.*, 2020).

Euthrophication is a kind of nutrient enrichment which ends to over nourishment in the ecosystem, both terrestrial and aquatic. It may lead the uncontrolled increase of biomass production or particular plant reproduction, for instance algae. When alga blooming occurs, it prevent the sunlight come into waters, then bothers the photosynthesis process and decrease the oxygen concentration (Ripaldi, 2015). The leading effect is the increase of water sediment due to accumulation of aquatic creatures. This study found the three biggest contributor of EP are unmanaged waste, leachate production in landfill, and wastewater of incineration. Ripaldi (2015) stated that beside transportation, leachate and the exhaust of incineration are the main impacts of EP contribution. This study found the composting leachate and wastewater of anaerobic digestion also play a role in eutrophic condition with the very small impact contribution (see Table 3).

Overall, each stage has impact contribution, whether it is high or small. The best scenario we can conclude is Scenario 1 due to the small contribution of impact compared to other scernarios. Scenario 1 is also potentially to be applied since the modification in increase of composting percentage and additional recovery gas in landfill. Moreover, the recommencation can be offer is the increase of effectiveness and efficiency of compoting and recycling process, increase of managed waste or reduce the unmanaged waste, and equiped an adequate leachate treatment in landfill.

4. Conclusion

GWP and EP are the significant impact contribution by the percentage respectively over 72%, and in the range of 1.70% to 5.46%. The most contributor stages of GWP and EP are unmanaged waste, improper gas recovery and leachate treatment in landfill, and also wastewater of incineration for EP. Comparing all scenarios, the founding is Scenario 1 is the best scenario due to the small contribution of impact and potentially implemented in Padang City. The shortcoming of this study may come from the data availability and collection for data inventory. Since data inventory is the core point of LCIA, upcoming studies can complete the lack of data inventory and depth of analysis, and discuss the other impacts provided in CML2001.

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