A life cycle assessment of biological treatment scenario of municipal solid waste in developing country (case study: Makassar, Indonesia)

IOP Conf. Series: Earth and Environmental Science 1263 (2023) 012070 doi:10.1088/1755-1315/1263/1/012070

A life cycle assessment of biological treatment scenario of municipal solid waste in developing country (case study: Makassar, Indonesia)

R Muis[1,*], I Rachman[1,2], T Matsumoto[1,3]

[1] Graduate Programs in Environmental Systems, Graduate School of Environmental Engineering, The University of Kitakyushu, Kitakyushu, 808-0135, Japan
[2] Department of Natural Science Education, School of Postgraduate Studies, Universitas Pakuan Bogor, 16143, Indonesia
[3] Research Center for Urban Energy Management, Institute of Environmental Science and Technology, The University of Kitakyushu, Kitakyushu, 808-0135, Japan

* c1dac405@eng.kitakyu-u.ac.jp

Abstract. Municipal Solid Waste Management (MSWM) is a significant challenge in developing countries, including Indonesia, where landfilling is the predominant waste treatment method. This study examines the case of Makassar City, where landfilling is still in use while composting is utilized to a limited extent. The research aims to evaluate and compare the environmental impact with three alternative scenarios involving biological treatment and life cycle assessment (LCA) processing. The scenarios were examined: Business as Usual Scenario (BaU), Landfill and Composting, Landfill and Anaerobic Digestion, Landfill, Composting, and Anaerobic Digestion. The study considers waste transportation, landfilling, anaerobic digestion, and composting within its system boundary, using annual waste processing as the functional unit. Environmental impacts assessed include global warming, acidification, and eutrophication. The findings indicate that the BaU scenario has the highest environmental impact, particularly regarding global warming, with 8,436,685.61 kg CO_2eq/year emissions. On the other hand, alternative scenario 3, which incorporates landfill management, composting, and anaerobic digestion, shows a relatively lower Global Warming Potential (GWP) emission. However, further measures are needed to effectively reduce emissions, such as implementing a cover for the compost pile and arranging the mixing.

1. Introduction

The challenge faced by developing countries in sustainable development is to create an efficient and economical waste management system. This is particularly applicable to urban waste, which is greatly influenced by the income level of the population, consumption patterns, and economic development [1-3]. The implementation of sustainable development principles in waste management is exemplified through the utilization of a waste hierarchy, which encompasses a range of initiatives focused on preventing the generation of waste, promoting preparatory measures for reuse, actively engaging in recycling practices, facilitating recovery through alternative processes, and ensuring the appropriate disposal of non-recoverable waste.

Each technology can have a positive impact in one aspect while simultaneously having a negative impact in another. To assess, compare, analyse, evaluate, and estimate the environmental impact of a product, a systematic approach commonly used is the Life Cycle Assessment (LCA) method [4]. The LCA study on testing five scenarios of material recovery facility (MRF)/recycling, composting, incineration, landfilling, and collection shows that composting is the most environmentally sustainable approach for MSWM [5]. Furthermore, other studies evaluated the effectiveness of composting and mechanical-biological treatment (MBT), and other management strategies. The study revealed that composting and MBT outperform incineration, landfilling, and other methods of waste management methods [6]. In other research, a comparison was made between landfilling and alternative MSWM options. The result found that landfills have the highest global warming potential (GWP) among various waste management approaches due to higher emissions of methane and carbon dioxide [7, 8]. Anaerobic digestion processing has several advantages, including the ability to reduce the need for landfill space, generate a source of energy, and mitigate pollution [9, 10].

In developing countries such as Indonesia, the capacity of waste management systems still needs to be improved, primarily centred on landfilling practices. Only 41-42% of the total waste generated, approximately 61 million tons per year [11], is transported and disposed of in landfill sites. Most cities in Indonesia, like Makassar City, utilize open dumping methods in these landfill sites [12], resulting in environmental degradation and risks to human health during their operation. This study utilizes LCA to determine the environmental impacts of several waste treatment scenarios, focusing on biological processing. Various waste management methods include landfilling with or without energy recovery, composting, and anaerobic digestion.

2. Methods

The method used in this study is LCA manual calculation with spreadsheets in Microsoft Excel. The stages of LCA consist of the following: determining goal and scope definition, system boundary determination, inventory analysis, life cycle impact assessment, and interpretation [13, 14]. The present study employs the LCA methodology to compare and evaluate multiple biological treatment scenarios, aiming to identify a viable scenario for future implementation. The primary objective is to develop three alternative waste management scenarios designed explicitly for MSWM Makassar. The three scenarios encompass distinct waste management approaches, including landfilling, composting, and anaerobic digestion. The current waste management practices at the Tamangapa Makassar Landfill include composting and landfilling. As part of alternative scenarios, anaerobic digestion is introduced as an additional waste management method.

2.1. Goal and scope

The study aims to compare the environmental impact of biological treatment in three scenarios to choose the best scenario with minimum emissions for waste management in Makassar City in the future. The scope of this study includes the transportation of waste from its source, waste management by composting using the windrow composting method, and waste treatment with anaerobic digestion as an alternative approach.

2.2. System boundary

Based on the waste composition in Makassar, most of the waste consists of organic waste that can be biologically treated. This study is based on government policies, where 70% of the waste generated will be processed through composting and anaerobic digestion. The system boundary of this study is limited to the open windrow composting method, which covers the entire process from the shredding process, curing windrow tuners, screening and stabilization, and until the compost is ready to use (Figure 1).

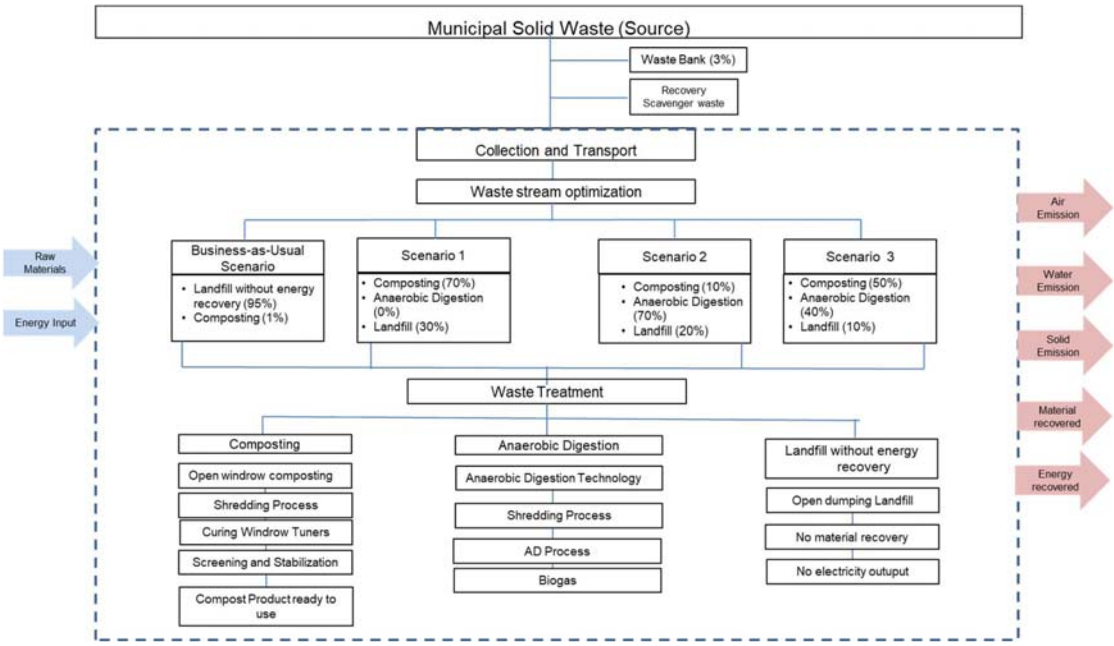

Figure 1. LCA system boundary

The application of compost outside the scope of this system is not considered. The anaerobic digestion process is limited to the shredding process, anaerobic digestion process, and until to produce biogas. As for landfill, the system employed is open dumping without energy recovery and electricity generation (based on existing conditions).

2.3. Scenario

The waste management scenarios consist of the BaU scenario, representing current waste management practices involving landfill and composting. Scenario 1 assumes 70% of waste to composting and 30% to landfill. Scenario 2 assumes 70% of the waste goes for Anaerobic Digestion, 10% for composting, and 20% for landfill. Scenario 3 assumes 50% of the waste for composting, 40% for Anaerobic Digestion, and 10% for landfill (Table 1). The scenario design considers several regulations in Indonesia, such as Presidential Regulation No. 83/2018 on marine debris prevention and Minister Regulation (MoEF) No. 75/2019 on waste roadmaps by producers [15], which promote the role of recycling and composting treatments.

Table 1. Scenario Assumed waste allocation for MSWM treatment in Makassar 2025

Scenario	Composting	Anaerobic Digestion	Landfill
1	70%	0	30%
2	10%	70%	20%
3	50%	40%	10%
BaU	1%	0	95%

3. Results and Discussions

3.1. Waste composition

The main composition of solid waste in developing countries, including Indonesia, primarily consists of waste materials that can naturally decompose, namely biodegradable waste. The municipal solid waste generated from developing countries primarily originates from households (55-80%), followed by market or commercial areas (10-30%) [16]. Analysis of waste composition reveals that the category of waste that dominates in terms of proportion is as follows: biodegradable waste represents about 73% of the total, non-biological waste, including plastics, cane, rubber, and metals, account for about 26%, and hazardous waste such as batteries represent a small fraction of about 1%. Figure 2 illustrates the waste composition specifically observed at Makassar.

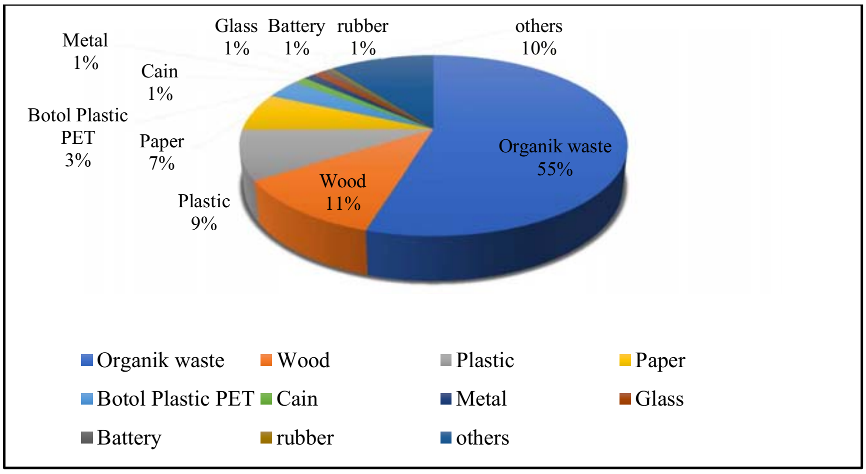

Figure 2. Waste composition

3.2. Inventory analysis

Before the analysis, the waste generation data of the city of Makassar is projected for 2025, which is the target year for National Strategy Policy (Jastranas). Jastranas is a roadmap of government policy that applies nationally in the managing household waste and similar garbage. Jastranas has set a target by 2025, and waste management should reach 100%, with a 30% reduction of waste and 70% treatment of waste [17]. To forecast the amount of waste generation in 2025 using data time series population (2017-2021) and population growth rate, then multiplied by the average amount of waste generation in Makassar [18]. The projection method used is the geometric method. The result of the projections is calculated at 70% as the input data to be analysed.

Makassar produced 410,291 tons of waste in total in 2021, or average1,139 tons per day. The projected waste generation for 2025 is estimated to reach 440,955.13 tons per year, equivalent to 1,208 kg per person per day, considering an average population growth rate of 0.58%. Based on the national strategic policy for the year 2025, Indonesia has set targets to reduce waste by 30% and treatment by 70%, amounting to approximately 308,668.59 tons per year.

The data on emission factors and equivalence factors at the midpoint stages were obtained through information from various relevant sources for this study. The data sources utilized include the Intergovernmental Panel on Climate Change (IPCC) report conducted to obtain emission factors for waste transport vehicles [19]; the IPCC report for shredding emission factors [19]; the IPCC report for composting and landfill emission factors [20]; the study for anaerobic digestion emission factors [21]; the research for heavy equipment emission factors [22].

The input data for waste processing per ton comes from resource use on transportation, composting, AD, and landfill operations. Each activity requires the input of resources such as fuel, water, and electricity in varying quantities. The specific details regarding the amount and volume of these resources can be found in Table 2.

Table 2. The resource input per tonne of waste processed

Operation	Input/Ton	Resources
Transportation	5.48 L	Fuel
Composting	2.17 L	Fuel
	38.85 L	Water
	1.29 kWh	Electricity
AD	2.17 L	Fuel
	1,440 L	Water
Landfill	0.86 L	Heavy Equipment Diesel

The difference in the amount of garbage is based on the percentage of each scenario. The resource used in the composting process, such as fuel, electricity, and water match the need in terms of the amount of waste input. As well as on anaerobic digestion process, and resources on landfill activity. Type of power in each scenario can be seen in Table 3.

Table 3. Input Activity in Each Scenario

Input	BaU	Scenario 1	Scenario 2	Scenario 3
Waste for processing (kg)	308,668,594.73	308,668,594.73	308,668,594.73	308,668,594.73
Waste for compost (kg)	3,086,686	216,068,016	30,866,859	154,334,297
Fuel (shredding process) (L)	6,790.71	475,349.64	67,907.09	339,535.45
Water consumption (L)	120,072	84,050,458	12,007,208	60,036,042
Electricity (kWh)	4,105.29	287,370.46	41,052.92	205,264.62
Waste for AD (kg)	0	0	216,068,016	123,467,438
Fuel (shredding process) (L)	0	0	475,349.64	271,628.36
Water consumption for AD (L)	0	0	313,298,623.66	179,027,784.95
Waste to landfill (kg)	305,581,909	92,600,578	61,733,719	30,866,859
Fuel (landfill activity) (L)	1,200	364	242	121

3.3 Interpretation

The impact categories presented in this study are divided into three sections: namely global warming potential (GWP), acidification (AP), and eutrophication. The first step in conducting Life Cycle Impact Assessment (LCIA) is categorizing emissions into the selected impact categories [23]. As categories CO_2, CH_4, N_2O, and CO are classified of global warming. The next step is the characterization process at the midpoint level. The characterization process is a quantitative measure to calculate various emissions within an impact category, in this case, using equivalency factors to ensure consistent units. The impact of global warming is expressed in equivalence to GWP (kg CO_2eq), acidification (kg SO_2eq), and eutrophication (kgPO_4^3eq).

The analysis results on existing BaU scenario showed the most significant impact on the GWP category of 8,436,685.61 kgCO_2eq; these emissions come from garbage transportation activities and landfill activity uses heavy vehicles. In 3 other scenarios, scenario 1 GWP value of 2,512,671.78 kgCO_2eq yields a higher emission impact than scenario 2, 2,327,498.49 kg CO_2eq, and scenario 3 is 2,142,325.19 kgCO_2eq (Figure 3). Global warming increases in scenario 1 due to the composting process, which uses fuel to shred waste materials. Emission values in the global warming category were the lowest in scenario 3, where this scenario was waste treatment with an almost equal ratio between composting and AD, and the amount of garbage dumped into landfill was only 10%.

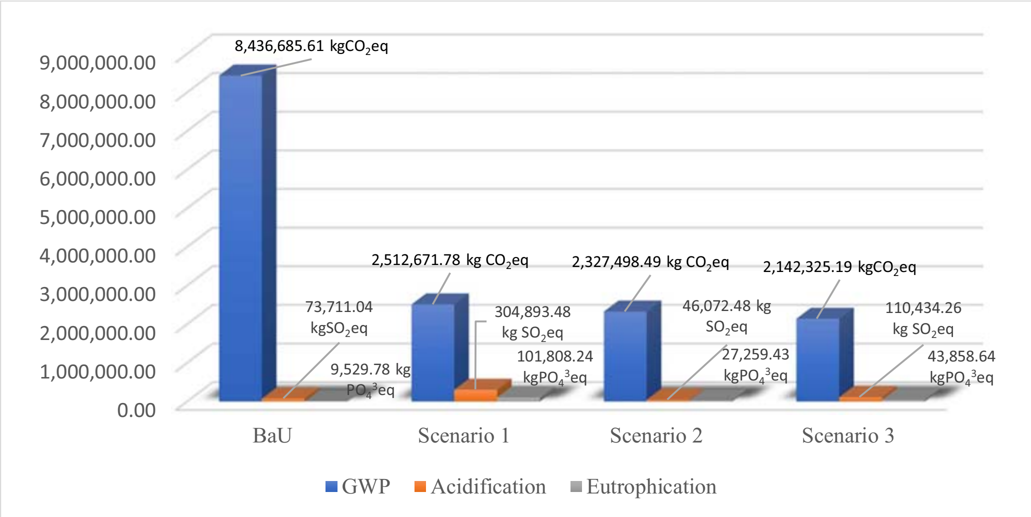

Figure 3. The emission value for each scenario

Acidification and eutrophication vary between scenarios because input values in the compounding process and AD differ in each scenario. The environmental impact category on acidification shows the most considerable value in scenario 1, at 302,893.48 kg SO2eq/year (Figure 3**)**. The lowest acidification category emissions in scenario 2 (46,072.48 kg SO_2eq/year) are from AD. In the eutrophication impact category, the highest value in scenario 1 is 101,808.21 kg PO_4^3eq/year, where the emission calculator comes from the compositing process. In this process, NH3 in composition contributes to the environmental burden of eutrophication. The most negligible impact on the eutrophication category was in scenario 2 (27,259.43 kg PO_4^3eq/year), dominated by the AD waste process. The eutrophication load on the compounding process has a more significant impact than the AD process.

Among the scenarios considered, in scenario 1, most waste processing uses compost processes, showing high emissions in all impact assessment categories, both levels of global warming, absorption, and eutrophication. Scenario 2, where waste processing mostly on the AD process, showed high GWP values but the lowest of acidification and eutrophication, among other scenarios. Scenario 3, a combination of compost and AD, shows low global warming values but higher categories of acidification and eutrophication, where the contribution of emissions comes from the composting process. Scenario 3 was chosen as the optimal waste management approach among the evaluated scenarios. However, mitigation efforts are needed to minimize the emissions from the composition process by arranging the mixing and placing the cover on the pile during the compositing process.

4. Conclusion

This study shows the results of the LCA analysis on the environmental impact of emerging global warming, with scenario 3 showing the most minimal emissions. However, other impact categories, i.e., acidification and eutrophication, show high emission values origin from the composting process. This scenario is recommended as an optimal waste management approach from other scenarios. Treatment is required to reduce the acidification and eutrophication emissions in the composting process, such as reducing the waste composting activity in the compositing process and providing a cover on compost stacks that can reduce NH_3 emissions.

IOP Conf. Series: Earth and Environmental Science 1263 (2023) 012070 doi:10.1088/1755-1315/1263/1/012070

Acknowledgments
We would like to express our sincere gratitude to the Matsumoto Laboratory, Graduate Programs in Environmental Systems, Graduate School of Environmental Engineering, The University of Kitakyushu, Japan, for their generous support in enabling the successful execution of this research.

References

[1] Marshall R E and Farahbakhsh K 2013 Systems approaches to integrated solid waste management in developing countries *Waste Manag.* **33**(4) 988–1003
[2] Otoniel B D, Liliana M B and Francelia P G 2008 Consumption patterns and household hazardous solid waste generation in an urban settlement in México *Waste Manag* **28** S2–S6
[3] Khair H, Rachman I, and Matsumoto T 2019 Analyzing household waste generation and its composition to expand the solid waste bank program in Indonesia: a case study of Medan City *J. Mater. Cycles Waste Manag.* **21**(4) 1027–1037
[4] Cellura M, Longo S and Mistretta M 2011 Sensitivity analysis to quantify uncertainty in Life Cycle Assessment: The case study of an Italian tile *Renew. Sustain. Energy Rev* **15**(9) 4697–4705
[5] Banar M, Cokaygil Z and Ozkan A 2009 Life cycle assessment of solid waste management options for Eskisehir, Turkey *Waste Manag.* **29**(1) 54–62
[6] Mendes M R, Aramaki T, and Hanaki K 2004 Comparison of the environmental impact of incineration and landfilling in São Paulo City as determined by LCA *Resour. Conserv. Recycl.* **41**(1) 47–63
[7] Zaman A U *Comparative study of municipal solid waste treatment technologies using life cycle assessment method*
[8] Dong J, Chi Y, Zou D, Fu C, Huang Q and Ni M 2014 Energy–environment–economy assessment of waste management systems from a life cycle perspective: Model development and case study *Appl. Energy*, **114,** 400–408
[9] Wilkie A C 2005 Anaerobic digestion: biology and benefits *Nat. Resour. Agric. Eng. Serv. Cornell Univ. Ithaca NY*, **NRAES-176** 63–72
[10] Evangelisti S, Lettieri P, Borello D and Clift R 2014 Life cycle assessment of energy from waste via anaerobic digestion: A UK case study *Waste Manag.* **34**(1) 226–237
[11] Yuliani M, Otivriyanti G, Yusuf N R, Fani A M and Purwanta W 2022 A Techno-Economic Study on the Application of Waste-to-Energy Incinerator in Indonesia (Case on City 'X') *J. Teknol. Lingkung.* **23**(2) 126–134
[12] Anggraini N, Muis R, Ariani F, Yunus S, and S 2021 Model of Solid Waste Management (SWM) in Coastal Slum Settlement: Evidence for Makassar City *Nat. Environ. Pollut. Technol*. **20**(2)
[13] Rebitzer G *et al.* 2004 Life cycle assessment *Environ. Int.* **30**(5) 701–720
[14] Finnveden G *et al.* 2009 Recent developments in Life Cycle Assessment *J. Environ. Manage.* **91**(1) 1–21
[15] Mustafa A B, Dong H, Zhang C and Fujii M 2022 Life cycle environmental benefit and waste-to-energy potential of municipal solid waste management scenarios in Indonesia *J. Mater. Cycles Waste Manag.* **24**(5) 1859–1877
[16] Hussein I A S and Mona M S M 2018 Solid waste issue : Source, composition, disposal, recycling, and valorization *Egypt. J. Pet.* **27**(4) 1275–1290
[17] *National Plastic Waste Reduction Strategic Actions for Indonesia*
[18] Kawai K and Tasaki T 2016 Revisiting estimates of municipal solid waste generation per capita and their reliability *J. Mater. Cycles Waste Manag.* **18**(1) 1–13
[19] Eggleston H S, Ed. 2006 *2006 IPCC guidelines for national greenhouse gas inventories* (Energy vol 2 Hayama Japan: Institute for Global Environmental Strategies)
[20] Eggleston H S, Ed. 2006 *2006 IPCC guidelines for national greenhouse gas inventories* (Waste vol 5 Hayama Japan: Institute for Global Environmental Strategies)
[21] Xu C, Shi W, Hong J, Zhang F and Chen W 2015 Life cycle assessment of food waste-based biogas generation *Renew. Sustain. Energy Rev.* **49** 169–177

[22] Diaz R and Warith M 2006 Life-cycle assessment of municipal solid wastes: Development of the WASTED model *Waste Manag.* **26**(8) 886–901
[23] Leibrecht S 2006 Information Model for the Integration of Ecological Assessments into Virtual Product Development *Int. J. Life Cycle Assess.* **11**(2) 142–142