Sriwijaya Journal of Environment
Article
ojs.pps.unsri.ac.id

Comparing Greenhouse Gas Emissions from Municipal Solid Waste Management Scenarios: A case of Palembang, Indonesia

Tuti Alawiyah[1,5], Febrian Hadinata[2], Daniel Saputra[3*], Ngudiantoro[4]

[1] *Doctoral Program in Environmental Sciences, Sriwijaya University*
[2] *Department of Civil Engineering and Planning, Faculty of Engineering, Sriwijaya University*
[3] *Department of Agricultural Engineering, Faculty of Agriculture, Sriwijaya University*
[4] *Department of Mathematics, Faculty of Mathematics and Natural Sciences, Sriwijaya University*
[5] *Regional Development Planning Board, Research and Development of Palembang City*
* *Corresponding Author: drdsaputra@unsri.ac.id*

Article history

Received	Received in revised form	Accepted	Available online
16 February 2023	12 March 2023	03 April 2023	26 May 2023

Abstract. Municipal solid waste (MSW) sector is one of the largest contributors to greenhouse gas (GHG) emissions. This study examines the extent of GHG emissions from five MSW management scenarios in Palembang city, i.e. (a) BAU scenario (existing), where 850.12 tonnes of MSW is disposed in semi-aerobic landfill, 37.73% in open incinerators, 1.17% in 3R facilities, and 61.1% others; (b) Scenario 1, where the landfill is upgraded to a well-managed semi-aerobic; (c) Scenario 2, where 100% collected MSW is disposed in well-managed semi aerobic landfill; (d) Scenario 3, where 70% MSW is disposed in well-managed semi aerobic landfill and 30% is taken to 3R facilities; and (e) Scenario 4, where all collected MSW is treated in incinerators. The methodology for estimating GHG emissions used IPCC 2006 (revised 2019). The result of the analysis shows that the existing condition (BAU) has the highest GHG emissions (730,767 tonnes of CO_2e). Scenario-4 has the lowest GHG emissions (117,954 tonnes of CO_2e). Therefore, 3R activities are the most important success factor for reducing GHG emissions in the MSW sector. Further financial and multi-stakeholder studies are essential for a sustainable approach in reducing GHGs emission from MSW management sector.
Keywords: Energy, fossil fuel, GHG, MSW, scenario

1. Introduction

Indonesia ratifies the Paris Agreement through Law No. 16/2016 and submits a Nationally Determined Contribution (NDC) document in which Indonesia targets a 29% (unconditional) and 41% (conditional) reduction in greenhouse gas emissions in 2030 [1]. The South Sumatra Provincial Government has published South Sumatra Governor Regulation Number 28/2018 concerning Regional Action Plans for Reducing Greenhouse Gas Emissions in South Sumatra [2]. The Palembang Municipal Government aims to reduce GHG emissions by 8% by 2023 and by 15% by 2030 (in terms of baseline emissions) [3]. The waste sector (solid waste, domestic wastewater, and industrial wastewater) is one of the contributors to GHG emissions, along with the energy sector, transportation, agriculture, and land use change. On a global scale, the complete elimination of waste contributes to approximately 3-4% % of human-caused greenhouse gas emissions [4] Different waste management scenarios exhibit substantial variations in greenhouse gas (GHG) emissions [5]. GHG emissions from the municipal solid waste (MSW) sector in Palembang City is caused by activities such as waste treatment at Sukawinatan landfills, open burning of waste by the community, and waste composting.

2. Material and Methods

This study compares GHG emission levels from BAU and four scenarios from Palembang MSW based on activity data and emission factors from each scenario. The activity data of existing MSW in Palembang are shown in Table 1. The emission factor, as shown in Table 2, uses the 2006 Intergovernmental Panel on Climate Change (IPCC) default value, revised in 2019 [4].

Table 1. Activity Data for Estimating GHG Emission from the Solid Waste Sector of Palembang City

Parameter (unit)	Data Type	Data Collecting Method
Population	Secondary	Population in the reference year 2030 is estimated using the geometry growth model, based on the total population of 2020 and average population growth 2010 – 2020
Waste generation rate (kg per person per day)	Secondary	Taken from Regional Policy and Strategy of Household Solid Waste and Likely Household Solid Waste Document of Palembang City [6]
Total waste to landfill (tonne per day)	Primary	Survey of MSW vehicle to landfill, conducted for four straight days. MSW weight in truck = car weight in the full state – car weight in an empty state. MSW volume is separated between weekdays and weekend.
Total composted waste	Secondary	Taken from National Waste Management Information System for Palembang City Data [7]
Total upcycled/ recycled MSW managed by the government	Secondary	Taken from National Waste Management Information System for Palembang City Data [7]
Total upcycled/recycled waste managed by the informal sector	Secondary	Taken from National Waste Management Information System for Palembang City Data [7]
Waste composition at the source	Secondary	Data survey of Environment and Cleanliness Agency of Palembang City [8]
Waste composition at a landfill	Secondary	Data survey of Environment and Cleanliness Agency of Palembang City [8]
The volume of waste collector car to landfill	Primary	Survey on vehicles in landfill, for four straight days
Fossil fuel consumption for waste transportation	Analyzed secondary data	Analysis of vehicle to landfill, consists of ritation, distance, and fuel consumption
Diesel oil consumption and grid electricity at composting facility	Secondary	Default value from Internal Affair Minister Regulation No. 07/2021 about Procedure in Calculating Retribution for Solid Waste Treatment [9]
Diesel oil consumption and grid electricity at the recycling center	Secondary	The default value in the worksheet of Emission Quantification Tool [10]

Table 2. Emission Factor and Calorific Value

Parameter	Qty	Source
Emission factor for grid electricity	0.84 tonne CO_2e per MWh	Emission factor for grid electricity, for Sumatera in 2019, Ministry of Energy and Mineral Resources (CM Ex-ante, OM = 0.75, BM = 0.25)
Emission factor for composting	4 kg CH4 and 0.3 kg N2O per tonne organic waste.	IPCC default value [4]
Emission factor for chemical fertilizer production (replaced by compost)	2404 kg CO_2; 0.45 kg CH_4; and 9.63 kg N_2O per kg chemical fertilizer	IPCC default value [4]
Avoided emission from the virgin production process	Varied	The default value in the worksheet of Emission Quantification Tool [10]
The calorific value of LPG	25.07 MJ/L	IPCC default value [4]
The calorific value of Gasoline	33.32 MJ/L	Ministry of Energy and Mineral Resources (Pertalite, RON 90)
The calorific value of Kerosene	35.25 MJ/L	Ministry of Energy and Mineral Resources
The calorific value of Diesel Oil	36.34 MJ/L	Ministry of Energy and Mineral Resources (Dexlite, CN-51)
The calorific value of Natural Gas	0.0333 MJ/L	IPCC default value [4]

To approximate greenhouse gas emission levels in units of CO2e, the metric Global Warming Potential (GWP) is used for a 100-year time horizon [4], i.e.: CO_2 = 1; CH_4 = 28; and N_2O = 265. Next, the scenario for MSW using the reference year 2030, as provided in the National Determined Contribution (NDC), is as follows:

- Business as Usual (BAU) scenario: based on existing conditions, 850 tonnes of waste per day is landfilled in semi-aerobic landfills (not well managed), 3 tonnes of organic waste per day is composted, 7 tonnes per day is recycled/reprocessed, and 370 tonnes per day is an untreated waste. Two landfills in Palembang city have been constructed in semi aerobic conditions but are not yet well managed.
- Scenario -1: The condition of the semi-aerobic landfill is improved. The other conditions are the same as BAU.
- Scenario -2: 100% of the collected MSW is stored and well managed in semi aerobic landfills (1178 tonnes per day), and 162 tonnes of waste per day is disposed of by the informal sector.
- Scenario -3: 70% of MSW is landfilled (938 tonnes per day), and 30% of MSW (402 tonnes per day) is disposed of by the informal sector and 3R (Reduce, Reuse, Recycle) Facilities, based on Palembang waste management policy and strategy [6];
- Scenario 4: 1000 tonnes of household waste per day is incinerated in an incinerator and the rest is landfilled and collected by the informal sector and 3Rs Facilities. Palembang Municipality signed a cooperation agreement in March 2022 with PT. Indo Green Power on energy recovery from MSW. This alternative is very costly and needs further study.

3. Result and Discussion

3.1. Waste generation rate of Palembang City

The average waste generation will not be the same between different regions or countries [11]. Based on the population of Palembang in 2020 (1,668,848 persons) and the average population growth 2010-2020 (1.38%) obtained from Palembang Statistics Agency using the geometric growth model, the population of Palembang in 2030 is estimated to be 1,913,990 persons.

Based on Palembang Mayor Regulation regarding The Policy and Strategy of Palembang City on Household Waste and Household-like Waste Management [6], the waste generation rate is 0.7 kg per person per day. With a population of 1,913,990 people, the total waste generation in Palembang in 2030 is estimated to be 1339.79 tonnes per day.

3.2. Waste composition

According to Damanhuri and Padmi [11], waste can be categorized based on its composition, such as wet weight percentage. The MSW composition at source in Palembang City is dominated by food waste (52.31%) and plastic waste (22.57%), followed by paper waste (7.82%) and diapers (7.26%). Other components are not significantly represented (< 5%). Food waste (30.56%) and plastic waste (22.64%) dominate in the landfill, followed by waste paper (14.84%), diapers (12.35%), garden waste (9.02%), fabrics and textiles (5.02%). Other components are not significantly justified (<5%) as shown in Table 3.

Table 3. Waste Composition at source (generated) and landfilled (collected)

Waste Components	MSW Composition (percentage of wet weight)	
	Generated	Collected
Food scrap	52.31%	43.71%
Paper	7.82%	14.96%
Nappies	7.26%	6.17%
Garden waste	0.91%	7.23%
Wood	2.58%	0.69%
Leather and textile products	3.08%	3.85%
Rubber and Leather	0.98%	0.78%
Plastic	22.57%	20.06%
Metal	0.75%	0.51%
Glass	1.28%	1.28%
Others	0.46%	0.76%
Total	100.00%	100.00%

Source: Environment and Cleanliness Agency of Palembang City [8]

3.3. Waste to Landfills

The results of the survey (December 5 - 8, 2020) show that the waste generated at the Sukawinatan landfill under BAU conditions is 850.12 tonnes per day (Table 4). The waste weight is analyzed by the difference between the weight of vehicles in full condition and the weight of vehicles in empty condition, which is measured by the scale in the landfill.

Table 4. Waste Volume in Landfill

Survey Days		Weight (tonne/day)
Survey day -1 (05/12/2020)	Weekdays (Saturday)	881.23
Survey day -2 (06/12/2020)	Weekend (Sunday)	664.22
Survey day -3 (07/12/2020)	Weekdays (Monday)	931.90
Survey day -4 (08/12/2020)	Weekdays (Tuesday)	830.19
Average week days		881.11
Average week end		664.22
Average = (6*Average weekdays + 1*Average weekends) / 7		850.12

In Scenario 1, the total amount of waste in the landfill is the same as in the BAU condition. The improvement is only in the condition of the landfill, from a well-managed semi-aerobic landfill to a non-well-managed semi-aerobic landfill. In scenario 2, 100% of collected MSW is in semi aerobic landfill and well managed. In Scenario 3, 70% of the total waste generated (938 tonnes per day) is landfilled. Under Scenario 4, all MSW is treated in an incinerator.

3.4. Treated waste in 3R facilities (composing and recycling)

Under BAU conditions, waste is not only landfilled, but also treated in 3R facilities, i.e., composted, reused as livestock feed, and recycled/reprocessed. The waste from 3R facilities is not directly carried out to Sukawinatan Landfill. The data on 3R activities in Palembang for 2020 are from the National Waste Management Information System. The data in this system is the result of online reporting completed by the Palembang Environment and Cleanliness Department. Table 5 shows the MSW in the 3R facilities.

Table 5. 3R Facilities and Treated Waste Volume

Facility Type	Number (unit)	Total Waste (tonne per day)	Compost Raw Material (tonne per day)	Raw material for cattle feed (tonne per day)	Raw material for recycle (tonne per day)	Raw material for upcycle (tonne per day)
Waste Bank	29	6.01	0.00	0.00	5.46	0.55
Composting Facility	23	0.11	0.05	0.05	0.00	0.00
TPS 3R	5	3/87	2.56	0.00	0.99	0.33
Formal Sector	57	9.98	2.61	0.05	6.44	0.88
Informal Sector	138	162.19	0.00	0.00	162.03	0.00
Total formal and informal sector	195	172.17	2.61	0.05	168.47	0.88

Source: Environment and Cleanlines Agency of Palembang City (2021)

Under Scenario 1 and Scenario 2, waste in 3R facilities (composting and recycling) has the same conditions as BAU (assuming no 3R facility). Under Scenario 3, 30% of MSW is reduced, which is equivalent to 402 tonnes of composted/recycled waste per day. Scenario 4 is estimated to incinerate 1178 tonnes of waste per day and compost/recycle 162 tonnes. The composted and recycled waste volume among various scenarios is shown in Table 6 below.

3.5. Incineration

Palembang Municipality has signed a cooperation agreement with PT. Indo Green Power to treat MSW for energy generation. The type of waste which will be managed thermally is household waste and household-like waste except for waste containing hazardous material, PVC, and aluminum foil. At least 1000 tonnes of waste per day will be treated in the incinerator (Scenario- 4). The type of incineration is continuous combustion with a stoker (data from PLTSa Sukawinatan feasibility study), using diesel oil for operation. The electricity recovery efficiency is 20%, taken from a case study of Yokote city in Japan [10]

3.6. Open Burned

In this study, MSW that cannot be collected is assumed to be openly incinerated. In the BAU condition and Scenario-1, about 317 tonnes of waste is openly burned (in front yards, on riverbanks, or at TPS) due to the lack of waste transport to the landfill. In

Scenario-2, Scenario-3, and Scenario-4, all MSW is collected by the Palembang Environment and Cleanliness Authority and/or treated by the informal sector (Table 6).

Table 6. Distribution of Waste Management (2030) in Various Scenarios

Scenario	Waste generated (tonne per day)						
	Landfilled	Composted	Recycled	Incinerated	Informal Sector	Open Burned	Total
BAU	850	3	7	0	162	317	1340
Scenario -1	850	3	7	0	162	317	1340
Scenario -2	1168	3	7	0	162	0	1340
Scenario -3	938	120	120	0	402	0	1340
Scenario -4	178	0	0	1.000	162	0	1340

3.7. Fossil Fuel Consumptions for Waste Transportation

MSW is transported by dump/crush/compressor truck using oil diesel (Dexlite, CN-51) and pickup/motorcycle using gasoline (Pertalite, RON 90). Fuel consumption is obtained by multiplying the number of transport vehicles to the landfill, distance (km/ration), and fuel consumption (liters/km). The vehicle distance is assumed to be 15 km per ritation. Table 7 shows the volume of waste transport vehicles to the landfill (survey result), while Table 8 shows the estimate of fossil fuel consumption to the landfill (BAU condition). For scenarios 1 to 4, it is assumed that the increasing fossil fuel consumption (compared to BAU) is proportional to the increasing waste volume to final disposal (landfill and/or incinerator).

Table 7. Waste transporting vehicle volume to landfill

Survey Day		Waste transporting vehicle type				
		Dump Truck	Armroll Truck	Compactor Truck	Pick Up	Tricycle with Container
Survey day -1 (05/12/2020)	Weekdays (Saturday)	169	32	2	104	28
Survey day -2 (06/12/2020)	Weekend (Sunday)	127	28	1	69	25
Survey day -3 (07/12/2020)	Weekdays (Monday)	140	58	1	100	25
Survey day -4 (08/12/2020)	Weekdays (Tuesday)	136	58	1	103	38
Average week days		148	49	1	102	30
Average week end		127	28	1	69	25
Average = (6*Average weekdays + 1*Average weekends) / 7		145	46	1	98	30

Table 8. Fossil Fuel Consumption

Vehicle Type	Vehicle Volume (ritation per day)	Distance (km per ritation)	Fuel Type	Energy usage intensity (litre per km)	Fuel consumption (Litre per day)
Dump Truck	145	15	Diesel oil (Dexlite)	0.33	719.16
Armroll Truck	46	15	Diesel oil (Dexlite)	0.33	229.11
Compactor Truck	1	15	Diesel oil (Dexlite)	0.33	6.36
Total diesel oil (Dexlite)					954.64
Pick Up	98	15	Gasoline (Pertalite)	0.11	160.99
Tricycle with Container	30	15	Gasoline (Pertalite)	0.07	31.05
Total gasoline (Pertalite)					192.04
Note: distance data is a preliminary estimation and need further study.					

CRE ITB (2001), PIE (2002) and RPC (2006) in Sugiyono [12]

3.8. Fossil Fuel Consumption in Composting Facility

The amount of organic waste generated as composting raw material (BAU) is 2.61 tonnes per day (Table 5), which is assumed to be food and garden waste, with a comparison of waste raw materials according to the composition of these two organic wastes at the point of generation (Table 3). Diesel oil consumption in the composting plant (shredder) is 1 litre per day (assuming 1 hour of operation per day).

Under BAU conditions, there are 23 composting units with diesel oil consumption of 23 litres per day; the mains power consumption with computer power 0.65 kW/unit; printer 0.01 kW/unit; lighting power 0.95

kW/unit, water pump 0.30 kW/unit and tool use 8 hours per day, then the power consumption in the composting unit is 12.88 kWh per day per unit. For a composting plant with 23 units, the electricity consumption in the network is 296.24 kWh per day. Compost production is projected at 400 kg per treated waste, with 100% of the compost used as plant fertilizer. For Scenarios 1 through 4, fossil fuel and grid electricity consumption are assumed to increase proportionally (compared to BAU) to the amount of waste produced at 3R facilities.

4. Conclusion

Based on the baseline scenario, total climate impact from GHG emissions per tonne of the generated waste is 730,767 kg of CO2-eq/tonne, while from scenario-1 is 627,617 kg of CO2-eq/tonne, scenario-2 is 720,472 kg of CO2-eq/tonne, scenario-3 is 610,277 kg of CO2-eq/tonne, and scenario 4 is 117,954 kg of CO2-eq/tonne. Scenario 4 has the lowest GHG emission level, while the highest GHG emission level is shown on the BAU condition. On BAU condition, less effective SWM management resulted in the high volume of untreated waste and open burned waste by the community. On scenario 4, all the SWM is treated by the formal and informal sectors. The 3R activities and 20 % energy recovery from incineration also has resulted significantly in reducing GHGs emission level. The present study aligns with the findings of recent studies conducted regarding greenhouse gas (GHG) emissions from waste management activities, for example Yilmaz and Abdulyahitoglu [13] suggested that MRF and incineration options would be helpful in reducing the total CO2 emissions. Furthermore, Lai et al. [14], also concluded that incineration was the most favorable scenario when compared to landfilling and recycling. However further study in financial and technical analysis for this scenario is needed in order to achieve a sustainable municipal solid waste management.

References

[1] The Republic of Indonesia, *Law Number 16 of 2016 concerning Implementation of Paris Agreement to The United Nations Framework Convention on Climate Change*. Indonesia, 2016.

[2] South Sumatra Province, *South Sumatra Governor Regulation Number 38 Year 2018 concerning Regional Action Plan on Greenhouse Gas Emission Reduction*. 2018.

[3] Palembang City Government, *Regional Regulation of Palembang City Number 2 Year 2021 concerning Revision of Regional Regulation Number 3 Year 2019 concerning Regional Mid-Term Development Planning Year 2018-2023*. 2021.

[4] IPPC, "2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories," Switzerland, 2019. doi: 10.1017/cbo9781107415416.002.

[5] Y. Liu, W. Sun, and J. Liu, "Greenhouse gas emissions from different municipal solid waste management scenarios in China: Based on carbon and energy flow analysis," *Waste Management*, vol. 68, pp. 653–661, 2017, doi: 10.1016/j.wasman.2017.06.020.

[6] Palembang City Government, *Palembang Mayor Regulation Number 73 Year 2018 Policy and Strategy of Palembang City in the Management of Household Waste and Household-like Waste*. 2018.

[7] "Waste Treatment Facilities in Palembang City," *Sistem Informasi Pengelolaan Sampah Nasional (SIPN)*, 2019. https://sipsn.menlhk.go.id/sipsn/public/home/fasilitas/komposting (accessed Sep. 02, 2019).

[8] Palembang City Government, "Sampling of Generation Rate, Composition, and Dry Matter Content of Domestic Waste in Palembang City," 2019.

[9] The Republic of Indonesia, *Internal Affair Minister Regulation Number 07 Year 2021 concerning Procedure in Calculating Retribution for Solid Waste Treatment*. 2021. [Online]. Available: https://peraturan.bpk.go.id/Home/Details/163295/permendagri-no-7-tahun-2021

[10] N. Menikpura and D. G. J. Premakumara, "Emission Quantification Tool (EQT) for Estimation of GHGs / SLCPs from Solid Waste Sector - Institute for Global Environmental Strategies," 2018.

[11] E. Damanhuri and T. Padmi, *Pengelolaan Sampah Terpadu.pdf*. Bandung: ITB Press, 2019.

[12] A. Sugiyono, "Prakiraan Kebutuhan Energi Untuk Kendaraan Bermotor Di Perkotaan: Aspek Pemodelan," *Jurnal Sains dan Teknologi Indonesia*, 2012, doi: 10.29122/jsti.v14i2.912.

[13] İ. H. Yılmaz and A. Abdulvahitoğlu, "Evaluation of municipal solid waste options in Turkey: Scenarios for energy recovery, carbon mitigation and consequent financial strategies," *Resour Conserv Recycl*, vol. 147, no. May, pp. 95–110, 2019, doi: 10.1016/j.resconrec.2019.02.029.

[14] K. Lai *et al.*, "Evaluation of waste reduction and diversion as alternatives to landfill disposal," *2014 IEEE Systems and Information Engineering Design Symposium, SIEDS 2014*, vol. 00, no. c, pp. 183–187, 2014, doi: 10.1109/SIEDS.2014.6829877.

.