Development of a low-emissions solid waste management strategy for East Jakarta, Indonesia

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Abstract. The relationship between municipal solid waste management and anthropogenic greenhouse gas (GHG) emissions has attracted significant attention worldwide. Solid Waste Management (SWM) systems contribute to GHG emissions at all stages of their management. This study aimed to provide an overview of the SWM system in East Jakarta and present guidelines for developing the right strategy for low-emissions SWM using three scenarios. GHG emissions were calculated for 2030 projections using the Emissions Quantification Tool (EQT) for Estimating Short-Lived Climate Pollutants (SLCPs) and Other GHG from the Waste Sector 2018 Version II, which was developed by the Institute for Global Environmental Strategies (IGES). Scenario 1, with 70% of waste entering the landfill, emitted 426.00 thousand tons CO_2-eq/year. Meanwhile, scenarios 2 and 3, which involved biological and thermal processing, respectively, emitted -161.17 and -133.48 thousand tons CO_2-eq/year. The differences in GHG emissions values between these scenarios were due to the type of processing process and processing capacity of each solid waste treatment technology. Furthermore, materials and energy recovery from several solid waste treatment technologies can provide GHG avoidance, resulting in a reduction of total emissions from SWM systems.

1 Introduction

Human activities have led to greenhouse gas (GHG) emissions accumulation in the environment. GHG emissions are considered during the production and use of a product, but they are also related to the end-of-usage period, i.e., the waste treatment process [1]. Furthermore, total solid waste disposal on a global scale accounts for approximately 3–4% of anthropogenic GHG emissions [2].

Solid Waste Management (SWM) system consists of several sequential stages, including collection, transportation, waste processing, and final disposal [3; 4]. Each stage of SWM produces GHG emissions [5]. Solid waste generation and composition (particularly carbon content), as well as the technology employed for waste handling and disposal, determine the final amount of GHG emissions from the SWM system [6]. Rapid urbanization, population growth, and socioeconomic development have led to increased waste generation worldwide [7].

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The East Asia and Pacific region, including Indonesia, generates the most significant amount of global municipal waste (approximately 23%) [8]. Most of waste generated in Indonesia comes from urban areas such as Jakarta, Bandung, and Surabaya [9]. DKI Jakarta, the most populous city in Indonesia, has around 15,978 people/km^2. It comprises five administrative cities and one administrative district, with East Jakarta Administrative City being the most populated at 3,056,300 people [10].

Based on data calculated by the Environmental Agency in DKI Jakarta Province, the estimated solid waste generation in East Jakarta in 2023 will reach 2,333.19 tons/day, primarily due to its large population [11]. Additionally, there is an annual increase in the amount of waste entering the Bantar Gebang integrated landfill system (TPST). Suppose the Business as Usual (BaU) pattern is implemented, the Bantar Gebang TPST, as the only landfill for the DKI Jakarta area, may become over capacity in accommodating waste.

Furthermore, SWM in East Jakarta still relies on landfill, which are the most significant source of GHG emissions [12]. Methane gas in landfill primarily emits from organic waste [13], with 60% being produced from the anaerobic decomposition process [14]. There is still a lack of both quality and quantity in waste reduction efforts and waste processing facilities.

To achieve optimal SWM and reduce environmental impacts, such as GHG emissions, it is necessary to conduct studies designed for the specific context of each locality. However, there have only been a limited number of studies that focused on reducing GHG emissions in the SWM sector at the city level in developing countries [14], including in the East Jakarta Administration City.

There needs to be more research on GHG emission estimates specifically for SWM systems in East Jakarta, with a comprehensive analysis of the SWM stages and site-specific data. Hence, it is necessary to calculate GHG emission quantification more comprehensively for SWM systems in East Jakarta and explore the design of SWM scenarios carried out to optimize GHG emission reductions from municipal waste management systems.

2 Methodology

2.1 Solid Waste Management (SWM) Strategies

SWM strategies for East Jakarta was developed into three types of waste management scenarios compiled in this study:

1. Scenario 1 – *Existing*: a solid waste management system where data are obtained from the East Jakarta City Regional Policy and Strategy (Jakstrada) report and considered a Business as Usual (BaU) scheme.
2. Scenario 2 – *Biological*: a design to improve solid waste management system by focusing on biological processing based on the composition of solid waste in East Jakarta, which is dominated by organic/biodegradable waste [15].
3. Scenario 3 – *Thermal*: a design to improve solid waste management system by focusing on thermal processing through incineration.

To prepare three SWM scenarios, a projection of solid waste generation for 2030 is employed based on per capita solid waste generation in DKI Jakarta, which is 0.76 kg/person/day with a waste density of 0.22 kg/liter [15].

Table 1. East Jakarta City Solid Waste Generation in 2030

Year	Number of Inhabitants (People)	Solid Waste Generation (Ton/Year)	Solid Waste Generation (Ton/day)
2030	3,581,981	993,641.53	2,722.31

To calculate the following GHG emissions, solid waste generation value in Table 1 above will be reduced by 0.17%, which is the target of limiting waste generation in East Jakarta. This target implies regulations restricting single-use plastic bags in markets, shopping centers, and convenience stores, which have been in effect since 2019. Therefore, the mass balance of solid waste generation calculation in East Jakarta for 2030 will be 2,717.5 tons/day.

Scenario 1 resulted in 1.5% unmanaged waste in East Jakarta, while scenarios 2 and 3 incorporated a system that achieved 100% managed waste. This aligns with the target specified in the DKI Jakarta Solid Waste Management Master Plan, indicating that no unmanaged waste has been subjected to scattered dumping or open burning. Table 2 provides a detailed overview of the differences in SWM mass balance among the three scenarios.

Table 2. Mass Balance Solid Waste Management Scenario Design

Solid Waste Management	Scenario 1 *Existing* (BaU)		Scenario 2 *Biological*		Scenario 3 *Thermal*	
	tpd	%	tpd	%	tpd	%
Generated Waste	2,717.5	100	2,717.5	100	2,717.5	100
Composting	0.9	0.03%	43.2	1.6%		
Recycling	654.3	24.1%	783.4	28.8%	397.0	14.6%
TPS 3R	2.6	0.1%	337.6	12.4%	88.7	3.3%
Incineration	19.8	0.7%			1,905.8	70.1%
Landfill	1,999.7	73.6%	666.6	24.5%	326.1	12.0%
Anaerobic Digester (AD)	-	-	756.9	27.9%	-	-
Black Soldier Fly (BSF)	-	-	129.7	4.8%	-	-
Uncollected Waste	40.4	1.5%	-	-	-	-

2.2 Data Source

This study used primary and secondary data to prepare scenarios and calculate GHG emissions. Primary data were employed in GHG emissions calculations from solid waste collection vehicles. These comprised data on fuel consumption and the weight and volume of waste collected by cart officers from the source to the TPS (Temporary Shelter) in the East Jakarta area. The data were not yet available in the official report of the East Jakarta City Government. Furthermore, they were collected through questionnaires and direct interviews with cart officers who employ motorized vehicles and operators at the selected TPS location.

Secondary data were obtained from the East Jakarta Solid Waste Management Regional Policy and Strategy Report (Jakstrada) 2021, validated, and then projected for solid waste generation in 2030 using a Business as Usual scheme. They included information on solid waste composition, the type and capacity of solid waste processing at the source and facility, the amount of waste transported to the Bantar Gebang TPST, and the fuel needed by waste vehicles.

2.3 Calculation of Emissions

The GHG emissions calculated in this study start from solid waste generation, solid waste reduction at the source (household scale), solid waste transportation, solid waste processing at facilities, and final processing at landfill. The calculated value only accounted for direct emissions from transportation and waste processing. However, indirect emissions from fuel and electricity consumption for the operational purpose at processing facilities were not considered.

The GHG calculation method in this study employed the Emissions Quantification Tool (EQT) for Estimating Short-Lived Climate Pollutants (SLCPs) and Other GHG from the Waste Sector 2018 Version II, developed by the Institute for Global Environmental Strategies (IGES). EQT tool was a GHG calculator using Microsoft Excel software according to IPCC 2006 guidelines and other internationally recognized emissions factors [16].

Several solid waste treatment technologies, such as biological processing with BSF (Black Soldier Flies) and TPS 3R (Waste Treatment Unit), were not available in EQT version II. Therefore, this study manually calculated their GHG emissions using emissions factors from a literature review and according to the 2006 IPCC guidelines.

In general, this study's GHG emission calculation formula was to calculate gross emissions from solid waste processing and waste transportation minus GHG Avoidance from material/ energy recovery from the solid waste treatment process. This was applied to obtain the net emissions in each stage of SWM for each scenario.

Three types of GHG considered and adjusted in this study were carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These gases were presented as thousand tons CO_2-eq/year using the Global Warming Potential (GWP) AR5 standard value. Figure 1 presents the calculation scheme for determining the net GHG emissions in each stage of SWM for each scenario.

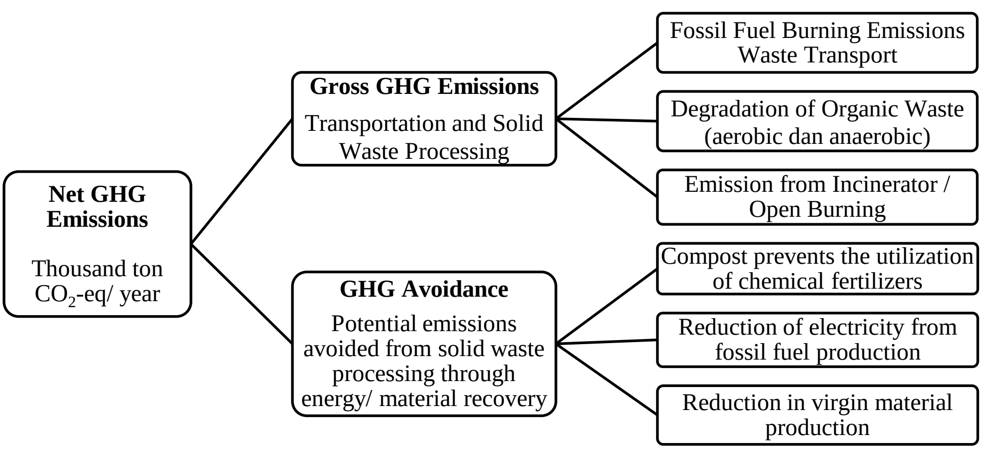

Fig.1. GHG Emissions Calculation Scheme

3 Results and discussion

SWM system emits GHG emissions in all stages, starting from generating, collecting, transporting, and processing to entering the final processing/ landfill. Various SWM methods can be a choice of strategies to improve waste services and determine the best scenario to apply for low emissions solid waste management system in a city.

This study discussed the design of existing SWM scenarios and the development of biological and thermal solid waste treatment scenarios to be developed in East Jakarta City in 2030, with a primary focus on reducing GHG emissions. Based on study calculations, the total net GHG emissions from the three scenarios compiled have different GHG emission values as an implication of the different types of technology developed in each scenario. Figure 2 provides a comparison of GHG emissions from the three scenarios.

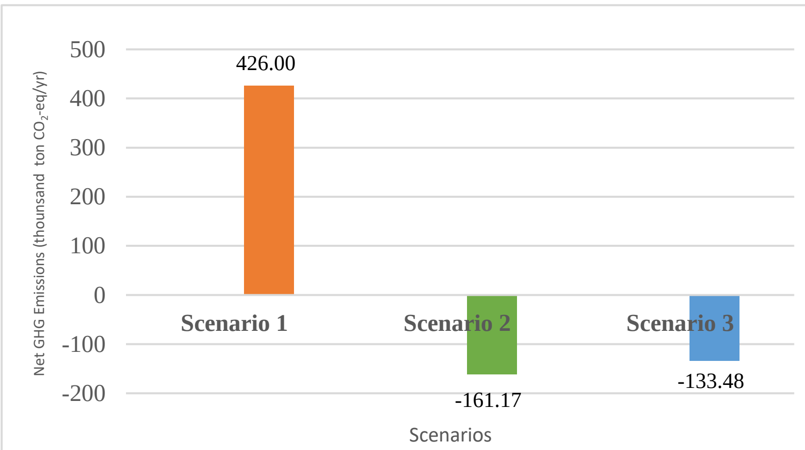

Fig.2. Comparison of Net GHG Emissions Based on Three Scenarios of East Jakarta Solid Waste Management 2030

The type of processing process and the processing capacity of each solid waste treatment technology becomes the main factors that cause differences in GHG emissions values between the three scenarios. In Scenario 1, which represents the current practices in East Jakarta City, landfill at the Bantar Gebang TPST remains the primary SWM system. This involves open dumping of approximately 73.6% of the total solid waste generation in 2030, as shown in Table 2. As a result, the existing scenario produces the largest GHG emissions at 426.00 thousand tons CO_2-eq/year compared to the other two. These come from CH_4 produced from the anaerobic decomposition of organic material in landfill that is poorly controlled and unused of landfill gas. The process produces about 60% CH_4 and 40% CO_2. Uncontrolled CH_4 emissions from the landfill have been listed as the second largest source of anthropogenic CH_4 emissions, attaining 19% of global CH_4 emissions (67–90 million tons of CH_4 per year) [11]. Finally, the GWP of CH_4 is 28 times greater than CO_2 [17].

Scenario 2 (*Biological*) provides the lowest GHG emissions due to the integration scheme of biological processing (composting, BSF, and anaerobic digestion) with recycling activities when considering the composition of East Jakarta City solid waste, which is dominated by organic waste. GHG emissions from biological processing are caused by the degradation of organic waste, where the majority is converted into CO_2. It is worth to note that these CO_2 emissions are biogenic and not included in the calculations.

Total net GHG emissions for scenario 2 were -161.17 thousand tons CO_2-eq/year. This negative value indicates the amount of GHG emissions avoided as a form of GHG emission reduction caused by material processes and energy recovery. The recycling activities in scenario 2 have a significant capacity of 28.8% of the total solid waste generation, which can prevent GHG emissions from virgin material production, resulting in -376.8 thousand tons CO_2-eq/year. Furthermore, using compost as a form of material recovery can also prevent GHG emissions from the production of chemical fertilizers. The energy recovery obtained from converting biogas into electricity through the anaerobic digester process can also avoid GHG emissions caused by conventional fossil fuel electricity production, resulting in a value of -46.3 thousand tons CO_2-eq/year.

For Scenario 3 – *Thermal*, which prioritizes solid waste processing through incineration, results in significant GHG emissions caused by waste burning in incinerator. CO_2 emissions from incinerator combustion come from carbon oxidation of waste derived from fossil fuels such as plastics, rubber, and textiles. The burning of biomass, including paper, food, and leaf waste, is considered as biogenic emissions, hence, is not included in the calculation.

During waste processing in incinerators, electrical energy is produced as a result of energy recovery. This process helps to avoid GHG emissions from conventional electricity production and leads to their reduction from the series of SWM system. As a result, scenario 3 will have total net GHG emissions of -133.48 thousand tons CO_2-eq/year by 2030, and this value is lower than scenario 1.

Table 3. Comparison of Net GHG Emissions on Three Scenarios of Solid Waste Management Stages in 2030

Waste Stages	Scenario 1	Scenario 2	Scenario 3
	(Thousand tons CO_2-eq/ year)		
Transport	24.7	17.1	26.3
Composting	0.1	3.0	
AD		-46.3	
Recycling	-314.7	-376.8	-191.0
BSF		0.1	
TPS 3R	-0.1	-7.0	-1.8
Incineration	1.9		-82.3
Landfill	706.0	248.8	115.3
Uncollected Waste	8.1		
Total GHG	**426.00**	**-161.17**	**-133.48**

When viewed from the comparison of GHG emissions from each stage of SWM for each scenario, as in Table 3, the landfill stage is the most significant contributor to GHG emissions from the three SWM scenarios in East Jakarta prepared. The difference in GHG emission values from the three scenarios for the landfill stage was dependent on the amount of waste that should be landfilled at the Bantar Gebang TPST. Scenario 1 (*existing*) had the highest amount of waste to be landfilled, which was 73.6% of the total generation. Meanwhile, in scenario 2, biological processing residues that should be landfilled were 24.5%. This value was still relatively high because the planned biological processing efficiency was only about 60-70%. In scenario 3, only about 12% of the total waste generation should be landfilled. This was because the processing efficiency through incinerators was quite large, at approximately 90% of the planned capacity.

Considering the stages of solid waste transportation, the three scenarios had relatively similar GHG emissions values. This was because the solid waste treatment facilities planned in scenarios 2 and 3 also still require waste collection and vehicles in their operational processes with the same fuel type. Specifically, gasoline was utilized for solid waste collection vehicles (Motor Carts or Pickup Cars), and diesel was used for solid waste transport vehicles (Garbage trucks).

Solid waste processing through waste recycling at Waste Bank facilities, TPS 3R (formal sector), and informal sector (scavengers/ stalls) provided significant GHG emissions reductions for East Jakarta City in all three scenarios. However, the smallest value of the avoidance from recycling was observed in scenario 3 (-191 thousand tons CO_2-eq/year). This was due to a decrease in recycling capacity, as the scenario was designed to meet waste feedstock needs for the continuous incineration process.

4 Conclusion

In conclusion, three scenarios were developed for solid waste management in East Jakarta. These included the existing scenario (open dumping at the Bantar Gebang), the biological scenario (biological processing and recycling according to the composition of waste), and the thermal scenario (incinerator processing).

Based on GHG emission viewpoints produced, scenarios 2 and 1 showed the lowest and highest emissions for the projected solid waste generation of East Jakarta City in 2030, respectively. CH_4 from the open dumping process at the Bantar Gebang TPST was the main cause of high emissions in scenario 1. The differences in GHG emissions between scenarios could be attributed to the type of processing process and processing capacity of each solid waste treatment technology. Furthermore, material and energy recovery from some solid waste treatment technology, such as recycling process, composting, AD, and incinerators, also provided GHG avoidance and reduced the total emissions.

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