# The role of recycling to minimize greenhouse gas emission in MSW management: A case study of Surabaya City

*Yunus Fransiscus Liem*[1,2*], *Aulia Ulfah Farahdiba*[3], *I.D.A.A Warmadewanthi*[1] and *Joni Hermana*[1*]

[1]Department of Environmental Engineering, Institut Teknologi Sepuluh Nopember, Surabaya 60111, Indonesia
[2]Center for Environmental and Renewable Studies, University of Surabaya, Surabaya 60293, Indonesia
[3]Department of Environmental Engineering, UPN Veteran Jawa Timur, Surabaya 60294, Indonesia

**Abstract.** Recycling, an upstream approach in the MSW management hierarchy, has become a concern for the Indonesian government. Following the guidance of national policy and strategy for MSW, a study on the impact of recycling to minimize GHG emissions was carried out for Surabaya City. By using the condition in 2020 as the baseline and upgraded waste composition data, the calculation indicates that increasing the recycling rate heightens the contribution of recycling in minimizing total GHG emissions. The increase of recycling rate from 24% to 30% will give emission reduction from 8.32% to 10.50%. A successful implementation of 30% recycling rate in 2025 will save -107,550 tonnes $CO_{2\text{-eq.}}$ In order to achieve the expected savings, it is suggested that 30 new ITFs be added to accommodate 248,228.85 tonnes of waste (assuming that each facility has a capacity of 20 tonnes per day).

## 1 Introduction

Climate change, a global environmental problem, has attracted worldwide concern. Getting involved in action for mitigation, Indonesia has ratified the Paris Agreement, an international commitment to emission reduction. The country pledged to achieve 29% and 41% emission reduction by 2030, independently and with international support [1]. The greenhouse gas (GHG) emission reduction program has been listed as a national priority and adopted for implementation at the regional or local level. Among the emission sources, the waste sector, primarily municipal solid waste (MSW), is considered crucial as it produces not only carbon dioxide ($CO_2$) but also two other major gases, which are methane ($CH_4$) and nitrous oxide ($N_2O$). Besides that, the scale of emission from MSW strongly correlates to population growth [2]. This means that a larger population will trigger more MSW generation, which will then determine the emission production. Total population in Indonesia grew from 255.59 million to 266.92 million in the period of 2015 to 2019.

* Corresponding author: yunus.fransiscus@gmail.com ; hermana@its.ac.id

During the same duration, it was noticed that total waste generation also increased from 64.40 million tonnes to 67.10 million tonnes which affected the raise of GHG emission of this sector, from 40.01 Gg tonnes to 43.78 Gg tonnes. Therefore, to increase the performance of MSW management, the Government of Indonesia introduced the National Policy and Strategy for Municipal Solid Waste Management in 2017. This initiative focuses on increasing MSW's handling and reduction rates as high as 70% and 30% by 2025 [3]. As listed at the top of the waste hierarchy management concept, reduction significantly minimizes GHG emissions. According to the national direction, efforts to reduce the amount of MSW can be made by limiting the waste generation at the source (reducing), reusing the waste, and converting "valuable" waste into new raw material (recycling), or so-called 3R activity. Among those options, recycling is deemed more practical, while intensive environmental education is required to encourage waste reduction activity at source (waste producer). However, the recycling rate in Indonesia is still deficient; it is noted that the value for the year 2019 was 11% - 13% [4]. A significant gap must be narrowed to achieve the targeted value of 30% of the recycling rate in 2025.

Some researchers pointed out the importance of recycling activity in reducing emissions from the waste sector. Lee et al. (2016) applied the Granger causal relation concept to test the correlation between waste recycling and GHG emission and found a negative trend [5]. Agreement on the result that the increasing recycling rate will result in declining GHG emissions from the waste sector has been expressed by several researchers [6-9]. Recycling was also indicated to bring significant GHG emission benefits in joint implementation with other treatments. Chen (2016) found that besides implementing waste to energy, recycling, especially for paper, metal, and food waste, brought notable emission reduction [10]. Among the proposed alternatives combination of MSW treatments, Xin et al. (2020) concluded that the application of incineration and recycling provided the highest emission reduction, as much as 70.82% [11]. Similarly, the involvement of recycling in the application of incineration and landfills was reported to give the most minor emissions [12]. Adding to that, Wang et al. (2020) were convinced that the extraction of valuable materials from well-sorted waste will both positively affect GHG mitigation efforts and provide economic benefit [13]. While efforts to foster recycling activity in Indonesia have been massively carried out, studies on the impact of recycling on minimizing GHG emissions are still limited. Considering that, this study is conducted to provide information on the role of recycling in reducing GHG emissions from MSW management. Life Cycle Assessment (LCA), a systematic method to quantify environmental impacts from a product or process, was applied. The implementation of LCA for determining and/or evaluating MSW management system has been widely reported [14]. This approach enables policy makers to select the best composition of treatments for optimum waste management system. Surabaya City, one of the metropolitan cities in Indonesia, was selected as the study area. The purpose of this study is then to give input to policy or decision-makers in regard to strengthening recycling programs, which is essential for reducing GHG emissions. Additionally, it is expected that the results of this study will be applicable to other metropolitan or big cities in Indonesia, depending on each waste composition.

## 2 Methodology

### 2.1 Study area

Surabaya is the capital city of East Java Province. As the second largest city in Indonesia, Surabaya has a total population of 2,874,314 inhabitants [15]. Total MSW generation in the same reference year was 811,255.10 tons [16]. Similar to other countries [17], the MSW management system in Surabaya City still relies on landfills. As described in Fig. 1, from the total waste generation, about 76.51% was discarded into landfills, involving 74.64% direct disposal and 1.87% scrapping residue from intermediate treatment facilities (ITF). A portion of 19.20% of waste generation still needed to be managed, while the recycling rate for organic and inorganic (including organic non-biowaste) was considered very low.

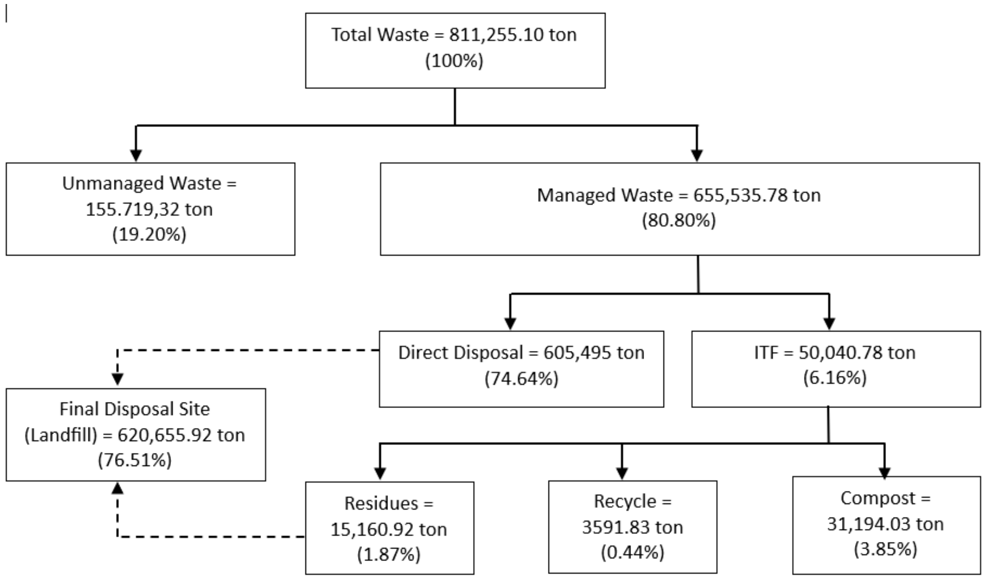


**Fig. 1.** Mass Balance of MSW in Surabaya 2020

ITF plays a significant role in supporting recycling activity. In this station, separation and compaction/packaging for recyclable materials (inorganic and organic non-biowaste) and treatment for biodegradable waste are being conducted. Recently, there have been 10 units of ITF (7 are so-called TPS3R – Waste Treatment Station with 3R Concept; 1 Super Depo; 1 Recycle Centre and 1 Separation House) in Surabaya City. Besides ITF, Surabaya has a composting house, another temporary station to receive and convert garden waste into compost products. At this moment, there are 26 units of composting houses in total. Improvements to the MSW management system in Surabaya have been delivered following National Policy and Strategy guidance. The implementation of the waste to energy (WtE) plan in the location of the final disposal site in October 2021 is considered a giant leap so far. However, significant efforts at the upstream level remain challenging and need to be encouraged by providing scientific information.

## 2.2 Goal and Scope

This study aimed to provide information on the impact of increasing recycling rate on GHG emission production. The designed scenarios were developed based on the guidance of National Policy and Strategy for MSW Management in Indonesia within 2020 - 2025. Calculations of GHG emission production and avoided from recycling activity were conducted by following the IPCC guidance. Since the study was concerned with the magnitude of the recycling rate, emissions from transportation were excluded. The functional unit (FU) generated total waste in the respective years. Nonetheless, updated information on waste composition from the field survey was utilized to ensure the relevancy of the study result. Supporting data for calculation and discussion were obtained from Environmental Agency Surabaya City and pertinent sources.

## 2.3 Scenarios and Inventories

The recycling rate was the main variable in the simulation, and the annual increase based on national targets was applied to the developed scenarios. Meanwhile, the other treatments were set alike as the condition of MSW management in Surabaya for the year 2020 (as displayed in Fig.1). The total amount of MSW in each year was calculated by multiplying the waste generation per capita value (from the year of 2020) and projected population for the respective years. Projection on population was adopted from the BPS Statistic Surabaya City [18]. The description of data for each scenario is presented in Table 1.

**Table 1.** Data description of scenario on recycling activity in Surabaya City

| Scenario | S-0 (2020) | S-1 (2021) | S-2 (2022) | S-3 (2023) | S-4 (2024) | S-5 (2025) |
|---|---|---|---|---|---|---|
| Population | 2,874,314 | 2,887,458 | 2,899,925 | 2,911,433 | 2,921,996 | 2,931,611 |
| Total MSW (ton/year) | 811,255.10 | 814,964.90 | 818,483.63 | 821,731.68 | 824,713.01 | 827,426.78 |
| Recycling Rate (%) | 1.62*) | 24 | 26 | 27 | 28 | 30 |

**) based on a calculation using waste composition data (Table 3)*

The recycling rate refers to the number of recyclable materials, including paper, plastic, glass, ferrous metals, aluminum, and textiles. To calculate this number, information on waste composition is needed; therefore, field surveys in the final disposal site and 9 ITS locations in Surabaya were conducted. The survey results for waste composition are shown in Table 2. Based on the information on waste fraction in the final disposal site, the total amount of recyclable waste in 2020 was 221,247.24 tons. It means that the recycling rate in 2020 was only 1.6%.

**Table 2.** Waste composition (percentage, %) in Surabaya City

| Waste Composition | Final Disposal Site | Average from 9 ITF locations |
|---|---|---|
| Food Waste | 34.48 | 37.94 |
| Garden Waste | 19.09 | 11.20 |
| Plastics | 16.51 | 17.44 |
| - PET | 0.90 | 2.39 |
| - PP | 0.86 | 2.05 |
| - PS | 0.41 | 0.79 |
| - PVC | 0.2 | 0.34 |
| - HDPE | 1.05 | 1.49 |
| - LDPE | 13.09 | 10.38 |
| Papers | 5.89 | 9.49 |
| - White paper | 0.23 | 1.07 |
| - Cardboard | 4.47 | 6.71 |
| - Tissue paper | 1.19 | 1.71 |
| Textiles | 3.46 | 2.32 |
| Rubber, Leather | 1.54 | 0.37 |
| Wood | 1.52 | 0.88 |
| Diapers | 9.77 | 9.45 |
| Glass | 1.01 | 1.37 |
| Aluminium | 0.26 | 0.75 |
| Metals | 0.14 | 0.07 |
| Others | 6.33 | 9.40 |

*Note : PET=polyethylene terephthalate; PP=polypropylene; PS=polystyrene; PVC=polyvinyl chloride; HDPE=high density polyethylene; LDPE=low density polyethylene*

The GHG emission from recycling activity was calculated by considering replacing raw materials and minimizing energy utilization. The calculation method referred to the IPCC guidance mentioned by Xin et al. (2020) [11]. In this study, emission factors from Prognos [19] for the accounted recyclable materials (Table 3) were used in the calculation process. Indonesia's specific emission factor for electricity generation, the JAMALI (Jawa Madura Bali) grid, was adopted. The value of this emission factor is 870 g $CO_{2\text{-eq}}$ per kWh.

**Table 3.** Emission factor for recycling (kg $CO_{2\text{-eq}}$ per ton waste)

| Emission factor | Paper | Plastic | Textile | Metals | Aluminium | Glass |
|---|---|---|---|---|---|---|
| Production | 180 | 1023 | 32 | 22 | 700 | 20 |
| Avoided | 1000 | 1437 | 2850 | 2047 | 11800 | 500 |
| Net | -820 | -414 | -2818 | -2025 | -11100 | -480 |

## 3 Results and Discussion

GHG emission calculation results of the MSW management system in Surabaya for the year 2020 are presented in Table 4. The biggest emission source was landfill, which contributed 89.60%, followed by unmanaged waste. Since finding the data on unmanaged conditions was difficult, the assumption of equal distribution to open burning and scattered/wild dump has been made. Wild dump practices induced more emissions because of the uncontrolled gas production, primarily from the anaerobic decomposition. Meanwhile, recovery initiation through composting for organic biowaste and recycling for inorganic and organic non-biowaste provided GHG emission savings. However, due to the minimum recovery rate, the total savings were still insignificant in reducing the total GHG emission.

**Table 4.** GHG emission of MSW management in Surabaya, 2020 (tonnes $CO_{2\text{-eq}}$)

| Condition/ Treatment | Waste/Treatment Type | Emission | Avoided Emission | Net |
|---|---|---|---|---|
| Composting | Food waste | 1747 | -1908 | -161 |
| | Garden waste | 967 | -1056 | -89 |
| Recycle | Papers | 138 | -765 | -627 |
| | Plastics | 2191 | -3078 | -887 |
| | Glass | 3 | -66 | -63 |
| | Metals | 0 | -37 | -37 |
| | Aluminium | 24 | -398 | -375 |
| | Textiles | 14 | -1280 | -1266 |
| Unmanaged | Open burning | 26,105 | 0 | 26,105 |
| | Wild dump | 76,642 | 0 | 76,642 |
| Final disposal | Landfill without gas collection | 928,991 | 0 | 928,992 |
| | Total | 1,036,823 | -8588 | 1,028,235 |

As for recycling activity, with only a 1.62% recycling rate in 2020, this upstream waste management strategy scarcely gave -5624 tonnes of $CO_{2\text{-eq}}$ saving or only reduced the total emission by as much as 0.54%. The simulation results on the recycling role following the annual target of National Policy and Strategy for MSW management in Surabaya are displayed in Fig.2. The GHG emission savings are also getting bigger by the increasing recycling rate. In no change condition for the other treatments, the contribution of recycling to reduce the GHG emission from MSW management in Surabaya gradually increases from 8.32% to 10.50% from 2021 to 2025.

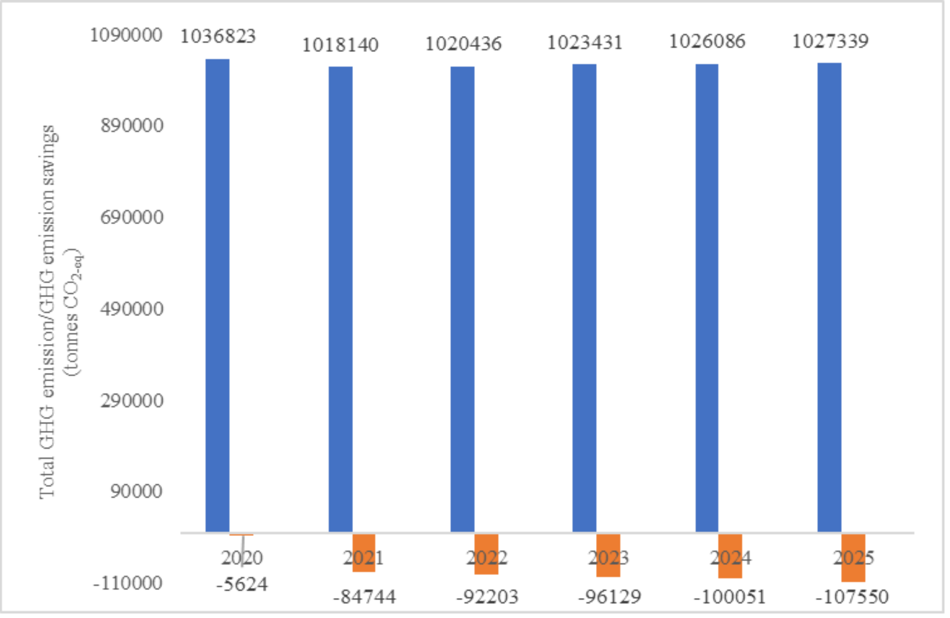


**Fig. 2.** Total GHG emission and emission savings from recycling activity in Surabaya

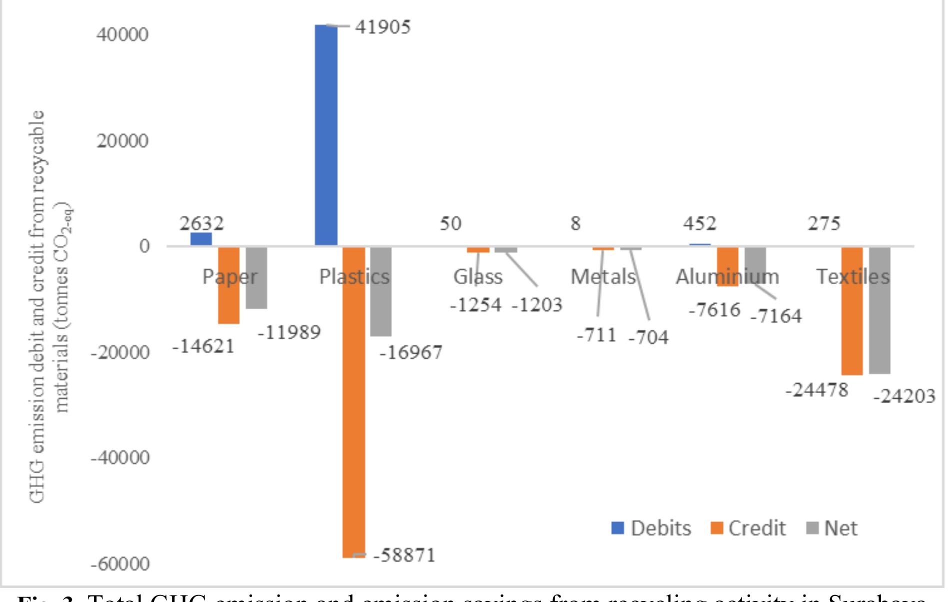


**Fig. 3.** Total GHG emission and emission savings from recycling activity in Surabaya

As shown in Fig. 3, among the recyclable materials in Surabaya, textiles proffer the most GHG emission net saving, which is -24,203 tonnes $CO_{2\text{-eq}}$. The complexity of the textile production process requires significant extraction of natural resources, resulting in crucial environmental impacts. The fact that major production countries still rely on fossil fuel utilization confirms this sector's need for recycling [20]. Avoidance of virgin materials will cut process complexity, and consequently, natural resources and energy usage will be diminished. Semba et al. (2020) reported that recycling $6.03 \times 10^8$ kg of used clothes reduced emissions by $6.60 \times 10^9$ kg $CO_{2\text{-eq}}$ [21]. Another study mentioned that a composition of 70% virgin material and 30% recycled cotton would achieve a 2.2% – 8.6% reduction in GHG emissions [22]. Plastics and papers are in second and third position, with -16,967 and -11,989 tonnes $CO_{2\text{-eq}}$ contributions of GHG emission net saving. Plastics, a prevalent material mainly for packaging, are made from oil. As for paper, which is used for various activities, it is a wood-based product. Recycling these two materials was essential to decrease the total emission from the MSW management system [23]. Recycling of the remaining three waste materials also positively impacts on the emission reduction effort. However, due to the fewer amount, the net savings of those three materials are less than the aforementioned wastes.

In order to achieve the total emission savings from recycling activity as much as -107,550 tonnes $CO_{2\text{-eq.}}$ in 2025, the municipality of Surabaya City has to collect at least 14,621 tonnes of paper, 40,982 tonnes of plastics, 2,507 tonnes of glass, 348 tonnes of metal, 645 tonnes of aluminum and 8,589 tonnes of textiles. Based on the waste composition data (Table 3), separation and collection in ITF locations are preferable. There is a substantial additional amount of garden waste in the final disposal site, making a notable difference in composition, especially for plastics and paper waste. This condition may happen since direct disposal of garden and park waste from residential and city areas is possible due to the limited capacity of composting houses. Currently, there are 10 ITFs in the Surabaya area with a total capacity of 81 tonnes per day or 29,565 tonnes per year. The Surabaya Municipality needs to increase its capacity since at least 248,228.85 tonnes of waste in 2025 has to be accommodated in ITFs for the successful recycling target. Therefore, a minimum of 30 new ITFs with a capacity of 20 tonnes per day per unit are necessitated. The importance of the provision of distributed ITFs in the Surabaya area is also reported by the study of Muhamad et al. (2020)[24]. This initiative will save GHG emissions from recycling but also cause emission reduction in landfills since less waste will be discharged into the final treatment. More importantly, these facilities can serve as education posts to raise environmental awareness of the surrounding community and, at the same time, provide new job opportunities. However, this intervention needs to be furnished by further policy development, especially to increase public and private partnerships without neglecting the participation of the informal sector. Community involvement through the waste bank concept has been formalized, but the role of the private sector (including mass-product manufacturers and recycling companies) should also be settled.

# 4 Conclusions

The role of recycling in minimizing GHG emissions from the MSW management system in Surabaya is tested by using LCA framework and IPCC guidance for the emissions calculation. Following the guidance of National Policy and Strategy, at a 30% recycling rate a saving of -107,550 tonnes $CO_{2\text{-eq.}}$ by 2025 could be reached. Separation and collection in the ITF location are considered more strategic based on the waste composition data. For that, 30 new ITFs with a capacity of 20 tonnes per day per unit in the Surabaya area are needed to accommodate 248,228.85 tonnes of waste. Beside recyclable materials, handling for organic biodegradable waste (food and garden waste) is also the concern of Surabaya municipality. As the major portion, this type of waste contributes significantly in GHG production. Aerobic (composting) and anaerobic digestion are two common approaches to convert the waste into valuable products. Identification and evaluation of

GHG emission from those two treatments are essential to assemble a sustainable MSW management in Surabaya.

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