Environmental impact of recycling plastic from waste banks in Surabaya, Indonesia

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Abstract. The waste bank is one of the formal sectors in the effort to reduce waste in the city of Surabaya. East Surabaya has 100 active waste banks, but there are 32 inactive waste banks. Plastic waste management in East Surabaya cannot be separated from the role of the formal and informal sectors. The waste bank activities support the waste recycling process and circular economy in the city of Surabaya. Plastic waste recycling activities can reduce waste but still have an impact on the environment. The purpose of this research is to analyze the environmental impact associated with recycling plastic waste through waste banks. The data collection method in this research is through surveys to waste banks, BSI, small scrap dealers, Large-scale enterprises, and recycling industries. The results of direct interviews can determine the process, generation, residue, and distribution of recycled waste. The process carried out, and the resulting residue was analyzed using the IPCC and journals to determine the resulting environmental impact.The results showed that plastic recycling through waste banks causes emissions to the environment. A total of 17.18 tonnes of plastic (0.11% of the total plastic waste in East Surabaya) resulted in GHG emissions of 74.19-74.34 tonnes of CO_2e.

Keywords: Environmental Impact, Plastic Waste, Recycling industries, Waste Bank

1 Introduction

Waste management is the most crucial issue for developing countries [1], especially Indonesia, which has the fourth-largest population in the world. The increase in the amount of waste is mostly caused by population growth, economic growth, and low awareness of waste management [2]. The low level of public awareness to reduce, reuse, and recycle at the source causes an increase in the number of management costs and land that need to be provided for TPA. Per capita, plastic consumption in Indonesia has reached 17 kg per year, with consumption growth of 6-7% per year [3]. In 2010, 3.2 million tons of plastic waste was produced. It is estimated that among plastic waste generated, 10-15% is recycled, 60-70% is put on final disposal sites, and 15-30% leaks into rivers, lakes, and the sea [4]. In waterways, Jakarta has reported that out of 165 tonnes of waste extracted from waterways, 41 tonnes (25%) involved plastics [4]. The composition of waste disposed of in waterways is 16% plastic bags, 5% plastic packaging, 1% plastic bottles, 9% other plastics, 4% glass and metal, 21% diapers, and 44% organic waste [4]. Indonesia is in an emergency state of plastic waste. The current condition of plastic waste in Indonesia can be called an emergency because it is the second-largest producer of plastic waste in the world [5]. The increasing presence of plastic waste is highlighted to increase recycling as a support for the circular economy [6]. Waste reduction in Surabaya through a combination of formal and informal sector roles. Waste bank, as a formal sector, plays a role in awakening the community to sort it out at the source. The waste bank is an inorganic MSW management system on a communal basis that encourages the public to take part in separating the waste and recycling the waste to boost its economic value [2].

The money generated is saved in the form of savings, which are given once a year on Eid al-Fitr holidays or used as village recreation. The waste bank sells waste to the Central Waste Bank or small scrap dealers as sector information. Several waste banks choose to sell waste to small scrap dealers because of the relatively higher selling price. Waste in a waste bank is sorted based on the type of constituent and the selling price. Plastic waste is categorized into sheets and non-sheet plastic. This plastic is further processed through large wholesalers and the recycling industry to form new products. The process of recycling plastic waste produces residues in the form of solid waste and wastewater. The residue that is discharged into the environment will produce GHG pollution. The waste management sector contributes to greenhouse gas (GHG) emissions mainly in the form of methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O) [7]. Theses emissions originate from several processes and components of the waste management cycle, from collection to material recovery, biological, thermal processes, and landfilling [8].

This study aims to analyze GHG emissions resulting from the recycling of plastic waste. Recycling of plastic waste starts from the waste bank to the recycling industry. The calculation of the resulting emissions can be used as recommendations for the government and stakeholders in making policies related to plastic waste processing through the formal and informal sectors.

2 Materials and Methods

2.1 Research Study Area

Surabaya is the second-most populous city after Jakarta. Surabaya City is divided into five zones, one of them being East Surabaya. East Surabaya comprises of residential, industrial, and educational areas, a combination that is distinct from other districts. The total area of the entire East Surabaya Region is 87,875 km^2, which is divided into seven districts and 41 sub-districts. The population reached 807,499 in 2018 [9]. East Surabaya is a district that has the highest number of waste banks compared to the others. Recycling of plastic waste in East Surabaya is inseparable from the sustainable roles of the formal and informal sectors. Central Waste Banks, small scrap dealers, large-scale enterprises, and the recycling industry play an essential role in the distribution and processing of plastic waste into new, reusable products.

2.2 Data Collection Methodology

The data in the study were obtained through measurement and direct interviews with the data source. Process data and the resulting residue are obtained from direct interviews with the main waste bank, small scrap dealers, large-scale enterprises, and the recycling industry. Waste generation and composition are measured in waste bank customers and non-customers. The number of waste bank customers in East Surabaya is 1901, and non-customers are 199,974 families. The chosen simple random sampling equation in calculating the number of sampling. In this study, the determination of waste banks, customers, and non-customers to be surveyed using the simple random sampling method. The sampling unit, as an element of a remote population, has the same opportunity to become a sample or represent the population. Respondents were randomly selected in a predetermined coverage area. The sample size can be found with equations 3.1 and 3.2.

$$n = \frac{N\, Z^2_{1-\frac{\alpha}{2}}\, PQ}{(N-1)D^2 + Z^2_{1-\frac{\alpha}{2}}\, PQ} \quad 3.1$$

$$D = \left(\frac{B}{Z_{1-\frac{\alpha}{2}}}\right)^2 \quad 3.2$$

where:
n = sample size, $Z_{1-\alpha/2}$ = standard normal distribution value (table z) at certain α (α = 5%), P = normal spread population (0.5), Q = 1-P, D = tolerable (absolute) error, N = population size, B = degree of error (35% used)

The degree of error was taken quite large because the COVID-19 pandemic hindered the research. Through the equation above, the sample number of waste banks, customers, and non-customers of waste banks is obtained. The proportion of distribution is based on the number of customers and population density for non-customers (Table 1).

Table 1. Distribution of the number of sampling

District	Samples of waste bank	Sample of waste bank customers	Samples of Non-customers of waste banks
Gubeng	6	4	4
Gunung Anyar	2	5	8
Mulyorejo	1	5	4
Sukolilo	7	4	6
Tenggilis Mejoyo	2	4	7
Tambaksari	2	4	14
Rungkut	1	1	7

2.3 Estimated GHG generated

The resulting GHG estimates are derived from residue management and recycling processes. The results of the GHG estimation are divided into several processes, namely the process of disposal to landfill, open burning of waste, emissions from wastewater, and emissions from fuel combustion. Emissions from the disposal process have an estimate of 0 $CO_{2(eq)}$ because plastic does not decompose quickly in contrast to organic waste, which is readily biodegradable to produce GHG [10]. Garbage that is burned or disposed of is explicitly plastic waste that can be recycled. The equation used is divided into 3, namely:

1. Emissions from open burning of waste

GHG emissions from open burning of waste are based on estimates of fossil carbon content, oxidation factors, and product-to-CO2 conversion factors. The GHG factor is divided into CO2, N2O, and CH4 emissions.

$$CO2\ emission\ (Gg/yr) = MSW \times \sum_i (WFi \times dmi \times CFi \times FCFi \times OFi) \times \frac{44}{12} \quad (3.3)$$

where: MSW= berat total sampah yang dibakar secara terbuka (Gg/tahun), WFi=total amount of wet solid waste of type j combusted (Gg/yr), dmi = dry matter contect in the wet waste combusted, CFi = fraction of total carbon in the dry matter (default plastic 67%), FCFi = farction of fossil carbon in the total carbon, OFi = oxidation factor (default IPCC = 58%), 44/12 = the convertion factor from C to CO_2, i = type of waste combusted.

$$N2O\ emission\ (Gg/yr) = \sum_I (Iwi \times EFi) \times 10^{-6} \quad (3.4)$$

Where: Iwi = the total weight of rubbish burned openly (Gg/yr), EFi = N2O emission factor (150 kg N2O/Gg of waste) for a waste of type I, and i = category or type of waste combusted (IPCC, 2006).

$$CH_4\ emission\ (Gg/yr) = \sum_I (Iwi \times EFi) \times 10^{-6} \quad (3.4)$$

Where: Iwi = the total weight of rubbish burned openly (Gg/yr), EFi = N2O emission factor (6500 g/t wet solid waste) for a waste of type I, and i = category or type of waste combusted [10].

2. Emissions from wastewater

The type of industry and production influences industrial wastewater emissions. This calculation requires data on the total organically degradable material in the wastewater and the emission factors for each treatment type.

$$CH_4\ emission\ (Gg/yr) = \sum_i [(TOW_i - S_i)\ EF_i - R_i] \quad (3.5)$$

where: TOWi = total organically degradable material in wastewater from industry i (kg COD/yr), Si = organic component removed as sludge (kg COD/yr), EFi = emission factor for industry i (kg CH_4/COD), Ri = amount of CH_4 recovered (kg CH_4/yr), i = industrial sector.

3. GHG emissions from burning stationary fuels

Sources of GHG emissions emitted by fuel combustion at stationary sources are CO2, CH4, and N2O caused by fuel and emission factors (Table 2-3). The amount of GHG emissions from burning fossil fuels depends on the amount and type of fuel burned [11]. The general equation used for estimating GHG from fuel combustion is as follows:

Energy consumption (TJ) = Energy consumption (physical sat.) x Calorific value (TJ/ physical sat.) (3.6)

GHG Emission (kg/yr) = Energy consumption (TJ/yr) x Emission Factor (kg/TJ) (3.7)

Table 2. Calorific Values of Indonesia Fuels

Fuel	Calorific Value
Premium*	33×10^{-6} TJ/liter
Solar (HSD, ADO)	36×10^{-6} TJ/liter
Diesel Oil (IDO)	38×10^{-6} TJ/liter
MFO	40×10^{-6} TJ/liter
Natural Gas	$1,055 \times 10^{-6}$ TJ/SCF $38,5 \times 10^{-6}$ TJ/Nm^3
LPG	$47,3 \times 10^{-6}$ TJ/kg
Coal	$47,3 \times 10^{-6}$ TJ/ton
Note: *) includes Pertamax, Pertamax Plus	

Table 3. Stationary Combustion Emission Factors in Manufacturing Industry

Type of Fuel	CO_2 (kg/TJ)			CH_4 (kg/TJ)			N_2O (kg/TJ)		
	Default	***Lower***	***Upper***	***Lower***	***Upper***	***Lower***	***Lower***	***Upper***	***Lower***
Natural Gas/BBG	56,100	54,300	58,300	1	0.3	0.1	0.1	0.03	0.3
Kerosine jets	71,500	69,700	74,400	3	1	10	0.6	0.2	2
Diesel (IDO/ADO)	74,100	72,600	74,800	3	1	10	0.6	0.2	2
Industrial/Residual Fuel Oil	77,400	75,500	78,800	3	1	10	0.6	0.2	2
Naphtha	73,300	69,300	76,300	3	1	10	0.6	0.2	2
Brown Coal Briquettes	97,500	87,300	109,000	10	3	30	1.5	0.5	5
Coking Coal	94,600	87,300	101,000	10	3	30	1.5	0.5	5

Source: IPCC, 2006

3 Results and Discussion

3.1 Generation and Composition of Household Waste

Each sub-district in East Surabaya produces different waste generation per household. Waste generation different because of the number of residents and the different lifestyles of each house. Reduction activities through waste banks, composting, and recycling can reduce the generation generated by each house. The average generation of generation in East Surabaya is 0.29 kg/ person/day, with a sample size of 75 households. The population in East Surabaya is 807,499 people with a generation rate of 0.29 kg/person per day, resulting in a total waste of 231,299.2 kg/day [9].

The composition of household waste is divided into food waste, plastic, paper, rubber, iron/metal, glass, cloth, B3, and residue (Fig. 1). Composition measurement is done by sorting and weighing each result according to category and expressed in percentage (%). The percentage of waste composition is obtained by comparing each type of waste and the total weight.

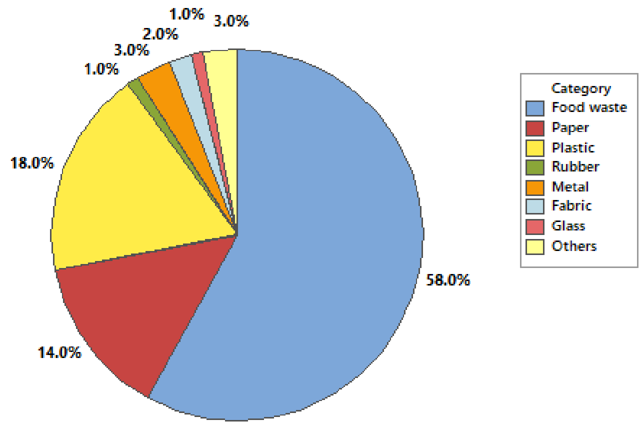

Fig.1 Composition of Household Solid Waste in East Surabaya

The resulting composition is similar to developing countries in Asia, with a dominant component of biodegradable waste ranging from 42 to 80%. The recyclable waste consists of paper (ranging from 3.6% to 30%) and plastics (ranging from 2.9% to 19.9%). The composition that can be recycled tends to increase in number due to changes in lifestyle and people's consumption [12].

3.2 Existing Condition of Recycling of Plastic Waste from Waste Banks

Waste processing through recycling from waste banks to the industry has an impact on the environment. The activities cause the impact of each process it carries out through sorting, enumerating, and processing it into new materials. The recycling process is illustrated through the diagram in Fig. 2.

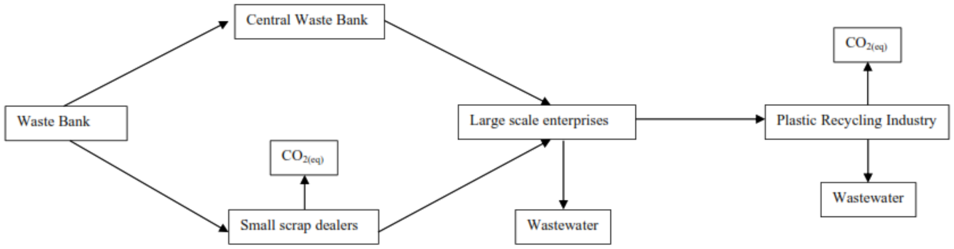

Fig 2. Plastic Waste Recycling Process Flow in East Surabaya

Waste bank activities in the community are usually carried out a week to once a month. This activity only carries outweighing and recording because the waste bank customers have sorted, cleaned, and categorized the waste being sold. This type of waste bank is only for those who sell to the Central Waste Bank (BSI). Usually, the waste bank that sells to small scrap dealers does not want to clean up the waste sold, for example, the label on the bottle so that it is sold in the general category. Like what happened at the Central Waste Bank (BSI), categorization was carried out in more detail and did not produce residues.

Activities in small scrap dealers are the same as those carried out by Central Waste Bank, namely sorting, categorizing, and cleaning bottle waste from attached labels. Small scrap dealers produce a residue in the form of plastic label waste. This residue is subjected to several treatments, namely being disposed of in the TPA, discarded and burned (50:50), and burned. These activities vary depending on whether or not small scrap dealers are in the garbage service. Most small scrap dealers located far from the road will burn the waste generated. Plastic waste disposed of in the landfill does not produce GHG emissions (IPCC, 2006). Emissions of 0.15 ton CO2e/year are generated from the combustion of 50% of the total generation, and the residue is burned 100%, resulting in emissions of 0.3 ton CO2e/tonne. Large-scale enterprises receive waste from both small scrap dealers and Central Waste Bank. Plastic waste is received in clean conditions, and the next process will be carried out, namely grinding the plastic. This grinding is done to increase the selling price to the recycling industry. The maximum residue from informal parties is 15%, and in this study, it uses 10% [13]. The estimates taken are estimated based on conditions in the field because there is no specific residue data in the informal sector. GHG emissions resulting from Large-scale enterprises are wastewater directly to the ground without prior treatment and emissions from fuel used for chopping. The total emission resulting from the chopping process of 4.81 tons of plastic waste is 18.24 tons $CO_{2(eq)}$/year.

The shredded plastic is sold to the plastic recycling industry. The industry is located in the City of Surabaya Urban Peri, namely Gresik, Mojokerto, Sidoarjo, and Pasuruan. The industry will carry out the next process to make plastic mills into finished or semi-finished products. The shrinkage in recycled plastic production is 15%, where 10% becomes wastewater, and 5% becomes waste [13]. GHG produced from 17.18 tonnes/year of plastic waste results in 55.8 tonnes $CO_{2(eq)}$/year. These emissions are generated from fuel emissions and the WWTP process because the disposal of plastic residues to the landfill does not produce emissions [10]. The total GHG produced from recycling 17.18 tonnes of plastic waste/year results in 74.19-74.34 tonnes of $CO_{2(eq)}$)/year (Table 2).

Table 2. Total Emissions from Each Process

Type of activity	Emissions (tonnes $CO_{2\,(eq)}$)
Waste Bank	0
Central Waste Bank	0
Small scrap dealers	0,15-0,3
Large-scale enterprises	18,24
Plastic Recycling Industry	55,8
Total Emissions from Plastic Processes	**74,19-74,34**

Every 1 ton of plastic production is 4.32-4.33 tonnes of CO2 (eq). This recycling process produces very few emissions compared to producing virgin plastic. According to Dormer et al. (2013), in producing 1 kg of virgin PET, the emission is 3.64 kg CO2 (eq) or 3640 tons CO2 (eq)/ton of virgin PET production. Products derived from recycling produce GHG from the process of collecting, sorting, washing (removing label marks), grinding, milled washing, and drying. The addition of production materials that come from recycling causes the resulting emissions also to decrease. According to Dormer et al. (2013), if plastic waste is disposed of to the landfill and incinerator without recycling, it results in an increase in the amount of carbon by 2.7%, from 1.538 kg CO2 (eq)/kg to 1.579 kg CO2 (eq) / kg. Recycling 32% of plastic waste can reduce the amount of carbon from 1.538 kg CO2 (eq) / kg to 1.524 kg CO2 (eq)/kg. Likewise, an increase in recycling by 50% can reduce the amount of carbon by 3%, from 1.538 kg CO2 (eq)/kg to 1.492 kg CO2 (eq)/kg (Dormer et al., 2013). It is estimated that recycling PET bottles can reduce GHG production by 1.5 tonnes CO2 (eq)/ tonne of recycled PET. An average net reduction of 1.45 tonnes CO2 (eq)/tonne of recycled plastic has been estimated to be useful for determining waste management policies. The analysis also shows that producing PET bottles from 100% recycled material can reduce the resulting emissions from 446 to 327 g CO2 (eq) per bottle. Mixing recycled plastic and virgin plastic is still profitable because it can reduce GHG by 0.5 tonnes of CO2 (eq) / tonne of product [14]. The use of virgin plastics as raw materials requires water, energy, and greater environmental impact than recycled plastics [14].

4 Conclusion

The estimation result of GHG from processing 17.18 tons/year of plastic waste is 74.19-74.34 tons CO2 (eq)/year. The resulting GHG is the total activity of the waste bank to the recycling industry. More GHG is generated from processing plastic ore into new products compared to recycling plastic waste.

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