Greenhouse Gas Estimation of Plastic Waste Reverse Logistic Networks System in Semarang City

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Abstract. Plastic waste in Indonesia has become global issues, where Indonesia itself has been stated as the second plastic waste polluter in the world. Semarang City, as one of the major cities in Indonesia, is also facing plastic waste problems. Reverse logistics network study for plastic waste recycling could be used as an alternative method to reduce emissions. In this study, the reverse logistics network of plastic waste is evaluated based on the estimation of greenhouse gases (CO2, CH4 and N2O) generated from recycling activities. The results showed that the most significant GHG emissions came from the plastic waste grinder (intermediates) for about 513 kgCO2eq/day. According to the calculations, the optimal number of informal recycling businesses is 224 units of scrap dealers, 358 units of small-scale enterprises, 23 units of large-scale enterprises, and 18 units of grinders. Total greenhouse gases produced from the 623 recycle business units were 932 kgCO2eq/day. Optimizing existing reverse logistics scenarios was needed to evaluate greenhouse gas emissions and mitigation scenario for reducing greenhouse gas emissions.

1. Introduction
Plastic waste is nominated as the second-highest waste production after organic waste in Semarang City. The limitations of Jatibarang Landfill in accommodating all trash in the city of Semarang underline the need to establish a system that can handle the problem of waste from its source. The regulation of production of goods accompanied by plastic packaging that is not easily implemented such as plastic has not been running optimally due to disorderly law enforcement and government uncertainty in preventing the formation of plastic waste from its source [1]. Although the formal recycling system has not yet been formed to its full potential, informal recycling has proven to be able to fill the position of the legal recycling system as well, especially in handling the plastic waste. Recycling activities utilize waste materials to be reprocessed into the same or other forms of products. Recycling waste benefits economically and environmentally and reduces dependence on the raw material. Recycling can reduce pollution, save energy, mitigate climate change and prevent biodiversity reduction [2,3]. Recycling can increase the lifespan of a product and can reduce resource consumption and avoid the costs used for disposal [4]. Recycling units in Indonesia are dominated by informal recycling consisting of scavengers, scrap dealers, enterprises, and waste grinder [5].

Reverse logistics, which is an alternative recycling system, has great potential to handle the plastic waste problem in Semarang city because it can be used as an instrument to design appropriate problem-solving scenarios and generate profits from an economic and environmental perspective. Reverse logistics activities aim at recycling of products so that parts or all items can be reused.
products can be in the form of products or packaging, such as end of life (EOL) products, end of use products, product recall, returns for stock balancing, returns for unsold products, reusable packaging, multi-trip packaging, etc. The reverse logistic scenario forces planners to create systems with minimum environmental costs and impacts. It prioritizes the concept of eco-efficiency to reduce the potential for waste and pollution [6–8]. Meanwhile, in Semarang city itself, the idea of reverse logistics is not yet fully understood and evaluated.

The flow of the informal sector in Semarang City has the potential to be improved by using the concepts of reverse logistics. The informal sector in Semarang city has not been able to reduce waste optimally because of the limited recycling facilities and the absence of clear regulations regarding the recycling business [9]. Therefore, network design is needed, which could be managed all plastic waste optimally [10]. In this study, a reverse logistic scenario design was performed in the existing condition as a form of initial identification of the reverse logistics network of plastic waste in Semarang city and the optimization of the number of informal recycling to increase its recycling rate. Also, this study also calculated the potential of greenhouse gases produced from the two scenarios formed as the basis for further research, particularly in developing integrated plastic logistics systems / reverse logistic.

2. Methods

This research was conducted by taking 41 samples from a total of 78 recycling business units in Semarang city, which were successfully identified based on data from the Semarang City Environment Agency. Of the 41 business units, each recycling business unit was categorized based on the amount of waste entering their facilities. Information about plastic waste flow (material flow) was constructed from in-depth interviews. Besides, this research also tried to parse the amount of recycling rate of each existing facility/business unit by developing a scenario which improves the existing reverse logistics network in Semarang City.

Carbon footprint is a methodology for estimating total GHG emissions in CO₂ equivalent to products in their life cycle from the manufacture of raw materials to the waste formed. Carbon footprint includes primary and secondary carbon footprint. Primary carbon footprint is a measure of direct CO₂ emissions, a measure of these emissions obtained from the burning of fossil fuels such as for energy consumption and transportation. In contrast, the secondary carbon footprint is a measure of indirect CO₂ emissions, which is obtained from the recycling of life from products used by humans, such as electricity to power machinery and electronic equipment. The carbon footprint unit is expressed in tons of CO₂ equivalent (tCO₂eq) or kg CO₂ equivalent (kgCO₂eq). The equivalent carbon dioxide (CO₂eq) is a universal unit of measurement to express the global warming potential (GWP) of each greenhouse gas produced in the GWP of one unit of carbon dioxide [11].

Greenhouse gas emission data were calculated based on instructions from IPCC 2006 (1) where the data inventory were data on the number of vehicles, vehicle models, fuel types and travel routes. These data were then processed to obtain greenhouse gas emissions by multiplying total activity with IPCC default emission factors. Based on the default method, CO₂, CH₄ and N₂O emissions from mobile and stationary sources are calculated by equations (1), (2) and (3):

\[ TE = fuel \text{ consumption} \times energy \text{ conversion} \times FE \]  
(1)

Where \( TE \) is total emissions (kgCO₂eq) and \( FE \) is the fuel emission factor (kg/MJ). The transportation used in managing plastic waste was road transportation. Emission sources from road transportation are private cars (sedans, minivans, jeeps, etc.), commercial vehicles (buses, minibuses, pick-ups, trucks and others), and motorbikes. As for immovable emission sources, emission factors from the fuel used were used.

In terms of electricity usage, the potential for indirectly generated greenhouse gases was calculated using equation (2):

\[ Energy \text{ Consumption (TJ)} = Electricity \text{ production (MWh)} \times SFC \times calorific \text{ value} \]  
(2)

Where energy consumption is the energy consumption of generating fuel in Terra Joule units (TJ), electricity consumption is the amount of electricity consumed or used (MWh), SFC is the fuel consumption at the plant in producing electricity production (Ton fuel/MWh), and the heating value is
the heating value of fuel (TJ/ton). The value of the electricity emission factor from coal fuel for CO$_2$ is 96,100 kg/TJ. The total emissions to find the carbon footprint from plastic management, are calculated using equation (3):

$$\text{Total Emission (kgCO}_2\text{eq)} = \sum [\text{Emission}_i \times \text{GWP value}_i]$$ (3)

Where total emissions (CO$_2$eq) are total emissions of all types of GHGs, Emissions are GHG emissions from types of GHGs, GWP$_i$ is the value of the Global Warming Potential of GHG types, and $i$ is a type of GHGs. The GWP value for methane (CH$_4$) is 28, and nitrous oxide (N$_2$O) is 265.

3. Result and discussions

3.1. An overview of plastic waste management in Semarang city

Waste generation generated by Semarang city’s resident reaches 835.32 tons/day where 21% is a plastic waste. The most significant waste generation in Semarang City is 449,819.03 kg/day (53.85%) organic waste. The organic waste consists of leaves, food scraps, tree branches, and so on. While the composition of the smallest generation of waste Semarang city is other types of waste amounting to 41,214.66 kg/day (4.93%), this different type of waste consists of rubber, glass, wood and so on outside of plastic, paper, metal and organic waste. Plastic waste takes the composition of garbage up to 179,762.23 kg/day (21.52%), which indicates the amount of plastic consumption in the people of Semarang City. Semarang City resident still throws waste without going through the process of sorting. Waste that has economic value and is thrown into the garbage bin will be collected by street scavengers or housing waste managers who work independently, while the garbage transporters will take the rest from the Department of the Environment as well as informal garbage transporters who work together with the local community to the place. Temporary waste storages (TWS) found in each district. From TWS, the waste will be brought by arm-roll / dump truck to Jatibarang Landfill to be landfilled.

![Figure 1. Composition of Each Type of Plastic Waste in Semarang City](image)

Plastic waste has seven types based on its recycling code, the types of plastic waste are PET (Polyethylene Terephthalate), HDPE (High-Density Polyethylene), PVC (Poly Vinyl Chloride), LDPE (Low-Density Polyethylene), PP (Polypropylene), PS (Polystyrene), and other types. The composition of the most substantial kinds of plastic waste is different types of waste (44.16%), the other types of waste consist of plastic packaging, children's toys, electronic devices, and household appliances (CDs, toothbrushes, etc.). The amount of other types of plastic waste generation is due to a large number of products that use plastic packaging such as snacks, candy wrappers, detergent wrappers, shampoo wrappers and so on (12). While the composition of the smallest type of plastic waste is polystyrene or PS (1.85%), the type of PS waste is found in styrofoam products both in places to eat and drink as well as items using styrofoam type plastic. The small amount of PS generation due to the use of styrofoam in daily activities is not so much so that this type of waste is not as significant as other types of waste. The percentage composition of each kind of plastic waste can be seen in figure 1.
3.2. Informal plastics recycling activities

Waste reduction has been carried out by a small number of residents who manage their waste by sorting and selling it to a waste bank or a scrap dealer, and making compost from its organic waste. The informal sector, which includes scavengers, scrap dealers, small-scale enterprises, big-scale enterprises and waste grinders, plays an essential role in reducing waste in Semarang city, especially plastic waste. Waste grinders are the first level intermediaries who will distribute large quantities of recycled materials per type to the raw plastic industry. According to research conducted, scrap dealers do not always sell waste to small scale enterprises but can go to waste grinders or factories/natural plastic industry. Recyclers are divided according to their management capacity shown in table 1.

Scavengers sell their garbage to scrap dealers, small-scale enterprises or big-scale enterprises who is near his location whereas scrap dealers will sell it to small enterprises or big-scale enterprises. The small-scale enterprises already have alternative sales options both to big-scale enterprises or factories. And the big-scale enterprises will send directly to the grinder or factory (5). The informal sector recyclers set up this business at their own expense. The processing of plastic waste into new raw materials does not yet exist in Semarang city, so small-scale enterprises or big-scale enterprises sell plastic waste to factories outside Semarang city.

![Table 1. Management capacity of recyclers](image)

| Recyclers        | Management Capacity (kg/day) | Management Capacity after Treatment (kg/day) | Optimal Amount of Recycling Business (Unit) |
|------------------|------------------------------|---------------------------------------------|-------------------------------------------|
| Scavenger        | < 25                         | -                                          | -                                         |
| Scrap dealers    | < 100                        | 347                                        | 224                                       |
| Small Scale      | 100-1000                     | 54                                         | 358                                       |
| Enterprises      |                              |                                             |                                           |
| Big Scale        | > 1000                       | 1,759                                      | 23                                        |
| Enterprises      |                              |                                             |                                           |
| Grinder          | > 2000                       | 2,149                                      | 18                                        |

3.3. Greenhouse gas emissions estimation

Greenhouse gas emissions from plastic waste recycling business come from three sectors, including transportation, machinery and electricity (13). Emissions from the transportation sector were estimated from transporting plastic waste to each processing site. This kind of emissions is one of the largest areas producing greenhouse gases in the plastic waste recycling system in Semarang city. Recyclers transport plastic waste from sources to their businesses using a variety of transportation, including pick-up cars, small trucks and large trucks to different destinations. As for machines, not all recycling agents use devices to treat waste. In this study, tools were only found in big-scale enterprises and grinders. In big-scale enterprises, the machines used are press machines and forklifts, while in grinders, the devices used are mills. For electricity, the primary use of power is the lighting.

Fuel consumption is the amount of fuel used by a type of vehicle at a certain distance. Vehicle selection variations depend on the weight of the waste each time it is transported. Big-scale enterprises and grinders choose to use large trucks to streamline transportation so that goods in their warehouses do not pile up and can be filled with new products. Small scale enterprises in Semarang city on average have a mode of transportation in the form of a pick-up car. This selection is also based on the weight of the one-time garbage transportation. Besides that, some smaller cities also do not have private vehicles to bring in traffic from buyers who provide transport services. The distance travelled by each recycling agent to the next place of management varies. Some recycling agents not only supply their merchandise to one place, but some choose two different locations. Some businesses want a distant place because
they have worked together for a long time, and the price offered is quite high. Another reason is that there are no factories that accept large-scale plastic and high rates in Semarang city.

Grinders are the type of business that uses the most fuel. This condition occurs because the waste that has been transported must have its market. In Semarang City, there are no plastic waste buyers who promise high purchase prices. In this research, plastic grinders supply plastic mill to the Cirebon factory in 4 times a week. Vast distances and extensive route result in high fuel use by grinders of up to 2,240 liters/month. Big-scale enterprises have a more considerable amount of fuel use than small-scale enterprises and scrap dealers. This activity is due to the average distance travelled by distant vehicles, and the more route. Likewise, with scrap dealers, trips to factories from all types of businesses have higher fuel consumption than to Semarang city. This phenomenon is because all factories that receive plastic waste are outside Semarang city, thus requiring large fuel consumption to transport plastic waste (14).

| Type of Business       | Total Emissions (kgCO₂eq/day) | Total GHG after Optimization of Number of Recycling Business Units (kgCO₂eq/day) |
|------------------------|-------------------------------|---------------------------------------------------------------------------------|
| Grinders               | 852                           | 513                                                                             |
| Big Scale Entreprise   | 244                           | 184                                                                             |
| Small Scale Enterprise | 16                            | 118                                                                             |
| Scrap dealers          | 10                            | 117                                                                             |
| Total                  | 1,122                         | 932                                                                             |

After going through the process of calculating the average per type of business of each sector, which includes management in the recycling sector is the machinery and electricity sector. The transportation sector was not added to distinguish on-site management and inter-site management. The sum of the machinery and electricity sectors can be seen in Table 2. The carbon footprint produced by the grinder has the most substantial value of 852 kgCO₂eq/day. This footprint is influenced in large part by the machinery sector. The mill has a roller that consumes vast amounts of fuel oil so that the emissions that arise are also significant. Unlike grinders, Big-scale enterprises that have an average carbon footprint of 244 kgCO₂eq/day because they only have tools in the form of presses and forklifts whose fuel consumption is not as big as grinding machines. A big-scale enterprise that has a carbon footprint of 16 kgCO₂eq/year does not have a plastic processor, so the value of greenhouse gas emissions is calculated based on electricity consumption.

The result showed that grinder was the business that has the most substantial greenhouse gas emissions to manage 1 kilogram of waste. The equipment used to process waste in the mill produces significant emissions. Meanwhile, a scrap dealer has a carbon footprint value per kilogram of waste that is higher than a big scale enterprise to manage one kilogram of waste. The resulting greenhouse gas emissions depend on the distance travelled by each transport, the farther the distance, the higher the greenhouse gas emissions. Large trucks have the most significant carbon footprint per kilometre among other vehicles because the amount of fuel consumption owned by large trucks is quite large. In contrast, pick-up cars are vehicles that have the smallest use of greenhouse gases compared to small vans and large trucks because of the little energy consumption per kilometre needed.

4. Conclusions
Optimization of the existing reverse logistics activities in Semarang city shows a great need for small-scale enterprises and scrap dealers to manage all of Semarang's plastic waste. The average emission produced by each informal recycling is reduced because total emissions are divided into more in each
informal recycling component. Although small-scale enterprises and scrap dealers are considered closer to settlements, the capacity of these small-scale enterprises is too small, and the purchase price offered is relatively minimal. Transportation is deemed to be ineffective because it can only transport small amounts of waste from each small-scale enterprises and scrap dealer. The results of this study encourage the need for further innovation to make a plastic-waste reverse logistics system better and more efficient especially to be implemented in Semarang City.

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