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An Analysis of the CO_2 Emission Abatement in Plastic Recycling System Using Life Cycle Assessment (LCA) Methodology: A Case Study of Bandung City, Indonesia

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Abstract

Global warming issue becomes a main issue in sustainable development planning for every country in the world. Indonesia as developing country has commitment to contribute in CO_2 abatement with proper development policies. Since May 2008 Indonesia has introduced new law of Solid Waste Management (UU No. 18/2008), the basis of waste management under this law is waste reduction to a landfill as the first priority. The highest waste material compositions in general are organic (50%) and plastic (15%) such as PET, PP, etc. In Indonesia, plastic is common to use as container/packaging. Plastic in Indonesia still using petroleum-based container/packaging and it contributes CO_2 emission in the life cycle. Thus, the recycling system on the plastic is significant in order to mitigate CO_2 emissions. That is, in this paper, we find the optimal system so as to reduce CO_2 emission in the plastic recycling system. The new scenarios on the recycling plastic in transportation sector and manufacturing sector will introduce in this study. In transportation sector, higher truck capacity will introduce to see the effect on CO_2 emissions abatement. In manufacturing sector, environmental friendly energy from new renewable energy will introduce to replace conventional energy sector. System Blue Tower (BT) technology through which the environmentally friendly electricity is supplied from municipal organic waste was argued. The proposal of a concrete system would be a CDM (Clean Development Mechanism) project in the near future. This study will model plastic recycling life cycle in Bandung City as a case study.

Keywords: Plastic Recycling, LCA, CO_2 abatement, Bandung City.

1 . Introduction

Since May 2008 Indonesia has introduced new law of Solid Waste Management (SWM), Undang-Undang No. 18/2008, the basis of waste management under this law is the concept waste reduction to a landfill as the first priority [5]. This new law should change the old common paradigm of SWM which is commonly done by collecting-transporting-landfilling. In so far, most of existing SWM system in Indonesian municipalities relies on the existence landfill. Most of wastes transported to final disposal sites are treated through open dumping, and it was estimated that only as much as 10% of landfill were treated through better system such as controlled open dumping sites. This main reason for this practice is due to the limitation of operational budget [6].

In any other major city in developing countries, the informal sectors may play important roles in some recovery effort on the usable materials of the waste. The recycling activity is engaged by housewives, waste workers (from cleansing division), vendors of used articles, and waste pickers. Middle-men or intermediary traders are found in all corners of the Indonesian cities to buy used articles directly door-to-door. Dry waste (inorganic waste) such as plastic waste is the most easily found on the waste recycling activities in large cities in Indonesia [6].

Based on research on 2006, the capture rate of plastic waste in Bandung, Indonesia is 34.33% [2]. It means that the 65.67% remains are still need to manage by proper handling by municipalities. On the other hand, from the global warming protection, Clean Development mechanism (CDM) is one of the opportunities for developing country to get financial and/or technological supports from developed countries. CDM scheme is focusing on CO_2 emission reduction and the CO_2 mitigation on plastic waste recycling will required if the developing countries want to take this opportunity as their policy.

2 . LCA Methodology

2.1. Goal and Scope

The goal of this study is to compare the CO_2 emission of conventional plastic waste recycling for new 2 scenarios due to the improvement of the transportation sector and/or manufacture sector. In this paper, the object study target area is in east of Bandung, one of the largest plastic recycling industry in Bandung. The functional unit was chosen as g-CO_2/kg-plastic.

2.2. System Boundary

FIGURE 1 shows the life cycle inventory flow chart for recycling industry systems (system boundary). The life cycle flow of the conventional system starts with collecting plastic waste from big collectors (intermediary traders) and then waste plastic is segregated by each category (type), after that continue to the grinding and washing processes in order to make the plastic into small size and clean. Wet small plastic will dried by ambient air (natural). The last process in this industry is making the small piece plastic into granule shape by thermal process. Through the duration of these processes, a raw material for making a new kind plastic product would be produced.

2.3. Optimal Solution

In the conventional system, scenario 1 and scenario 2, CO_2 emissions from transportation sector are assumed to be due to the fuel consumption of truck, which is indicated as a function of the loading rate of weight. In this model design the loading rate is 0.5 (scenario 1), 0.5-0.7 (scenario 2) and the truck capacity is 4 ton truck in the conventional system and scenario 2 and 10 ton truck introduced in scenario 1. The fuel consumption rates calculate based on equation (1):

$$fFC\,(\lambda) = a\lambda + 2b \qquad (1)$$

Where, the CO_2 emission coefficient for 4 ton truck a(=267.99 g-CO_2/km); b(=275.36 g-CO_2/km and for 10 ton truck a(=669.96 g-CO_2/km);b(=476.35 g-CO_2/km) are constants on the fuel consumption of the truck. On the origin and destination (OD) data for each area (Kecamatan) their distance were estimated due to the website of www.maps.google.com. The optimal solution calculated by following equation (2):
$Co_{2\ benefit/detriment} = CO_{2(conventional)} - CO_{2(new\ scenario)}$ (2)

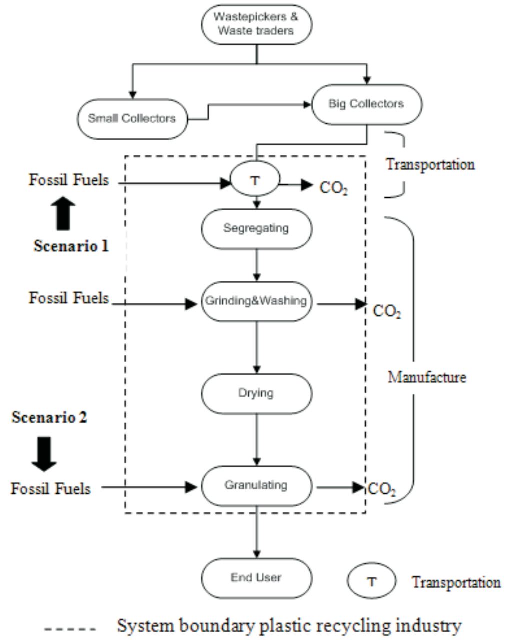

Figure 1. System boundary of the study

3 . Simulation Condition

3.1. Conventional System

The recycling industry located in East Bandung Area (see FIGURE 2) and it has stock capacity of 70 ton/week. The industry is collecting the plastic waste at 9 point of big collector and using seven trucks (4 tons capacity) to carry the plastic. In the average, each truck travels 5 times a week. The plastic collected is segregated manually to each category before it processed to grinding and granulating machines. Here, CO_2 emission from lifecycle of the recycling industry is shown in Table 1.

Waste collection contributes to 6.4% of CO_2 emission, grinding process contributes to 11.54%, and granulating process contributes to 82.06% (see FIGURE 3). If we separated into 2 sectors, the transportation sector contributes to 6.4%, and manufacture sector contributes to 93.38% of CO_2 emission (see FIGURE 4)

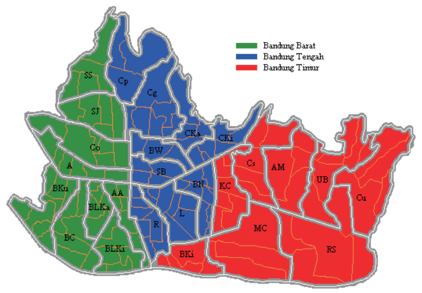

Figure 2. Location of study

Table 1. CO_2 emission at plastic recycling industry (unit: g-CO_2/kg-plastic)

Stage	CO_2	Sector	Fuel
Waste Collection	9.55	Transportation	Diesel
Grinding	17.22	Manufacture	Diesel
Granulating	122.4	Manufacture	Electricity
TOTAL	149.17		

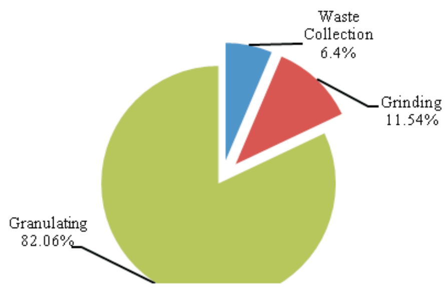

Figure 3. Percentage CO_2 emission in each process

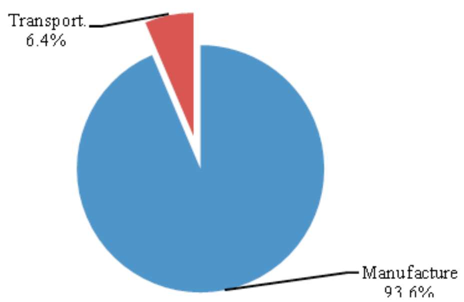

Figure 4. Percentage CO_2 emission in each sector

3 1. Scenario 1 : Optimization of Transportation Sector

The objective of first scenario is to minimize CO_2 emission in the transportation sector. Changing the truck capacity of conventional system, 4 ton truck to 10 ton truck, can reduced CO_2 emission 10.92% or 0.7 % from the total whole life cycle. For the detail results shown in TABLE 2.

Table 2. Effect of changing truck capacity

System	Truck Capacity	CO_2 emission (g-CO_2/kg-plastic)
Conventional	4 ton - truck	9.55
Scenario 1	10 ton - truck	8.55

3.2. Scenario 2: Optimization of Manufacture Sector

Second scenario introduced the biomass energy (Blue Tower gasification process) for supply energy demand in recycling industry. In Bandung, one of potential material to use is Compost (humus) from municipal solid waste. Bandung city produce approximately 7500 m^3 of solid waste per day and the organic contain 60-70% [7]. All organic material will have a biodegradation process from organic complex to simple mineral and the process can accelerated by composting process.

Compost usually used for fertilizer. However, in case of Bandung city, the market of compost would be still too low and people think it is not a potential as one of source of income [6]. Composting process has several methods and in this paper we assumed that the composting is done by household by cutting the waste, kept in the composting bin, and mixing for around 2 weeks to become compost. Referring to this method, composting process will not require energy or produce CO_2 emission.

Based on the chemical characteristics of Compost in Table 3 [8], this study will design the biomass gasification plant with Blue Tower (BT) process [4]. At the first step the BT plant scale is fixed 5 tons/day and only one. The compost material collected from 8 point sources area in East Bandung (see FIGURE 2). The utilization of compost in BT plant was only 16.67% from total annual compost yield. The optimal energy system on the total energy (KWh/year) and CO_2 emission (ton-CO_2/year) as output was simulated (1000 times) through the uncertainties of loading rate of truck (%). Here, the GAMS ver.23.0 software was used to construct and simulate this optimization model.

As a result, the total energy was 1.86 x 10^6 KWh/year. The CO_2 emission results changed through the number of loading rate (see FIGURE 5). The highest CO_2 emission (21.48 g-CO_2/kg-plastics) reaches if the loading rate is 0.5 (the lowest loading rate). And the lowest CO_2 emission (21.30 g-CO_2/kg-plastic) reaches if the loading rate is 0.7 (the highest loading rate). If we compared this CO_2 emission value to the conventional system in energy sector, this scenario would be reduced 67.77% CO_2 emission (highest loading rate) or 67.65% CO_2 emission (lowest loading rate).

Table 3. Characteristics of compost material [8]

Characteristic	Unit	Compost	Leaves
C	wt%	32.37	42.5
H	wt%	3.83	5.86
O	wt%	26.91	42.99
S	wt%	0.39	
N	wt%	1.21	0.98
Cl	wt%	0.65	0.4
Ash	wt%	34.64	
Total	wt%	100	100
Moisture	wt%	40.35	10.78
Heating Value	MJ/kg	8.76	17.25

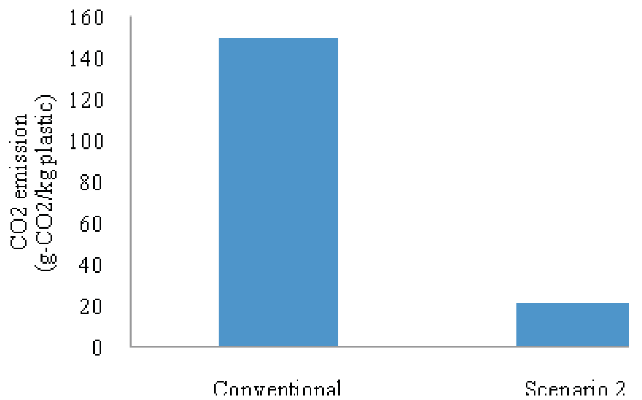

Figure 5. Effect of biomass energy

3.3. Cost Comparison Renewable Energy

Table 4 shows the comparison of CO_2 abatement cost for renewable energy in Indonesia. The lowest cost is geothermal energy and the highest is Wind Energy. On the other hand, Blue tower gasification (BT) cost from this study shows twice than geothermal energy and Solar PV cost is higher than BT. Based on the resources potentiality in Bandung City and cost abatement cost aspects, Blue Tower Plant is more feasible than the other renewable energy.

Table 4. CO_2 Abatement Cost Comparison

No	Renewable Energy	Cost (Yen/ton CO_2)
1.	Blue Tower	13,626
2.	Wind Energy	102,717 -329,967
3.	Solar PV	16,400
4.	Geothermal	5,800

4. Conclusion

In conventional recycling plastic system shows that the highest contributor in CO_2 emission is from manufacturing sector in compare to transportation sector. The manufacturing sector contributes 93.6% CO_2 emission and transportation sector contributes 6.4%.

Optimization transportation sector (Scenario 1) by changing truck capacity can reduce CO_2 emission 0.7% from total life cycle. In manufacturing sector, grinding process contributes 11.54% CO_2 emission from diesel fuel and granulating process has significant contribution 82.06% from electricity power. Optimization in manufacturing sector (Scenario 2), we model the Blue Tower gasification Plant in Bandung. From this scenario CO_2 emission can be reduce to 68% from the total lifecycle.

Other renewable energy resources are also promising in Indonesia. Based on CO_2 abatement cost, Biomass Energy (Compost) gasification process has a lower cost than Solar PV energy.

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