

Life Cycle Assessment and Energy Efficiency from Industry of Plastic Waste Recycling

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ABSTRACT. The high use of plastic products is currently causing uncontrolled accumulation of plastic waste so that an effort is needed to minimize the negative impacts caused to the environment. One of the appropriate efforts in processing plastic waste is recycling to produce a variety of useful products. Each stage of the process in managing plastic waste recycling starts from collecting raw materials to producing a new product for consumers requiring energy that can be calculated and analyzed for their impact on the environment using the LCA method. From this study can be concluded that the plastic recycling industry as one of the efforts in reducing the generation of plastic waste to the environment consists of 3 (three) main stages, namely the stages of enumeration, the distribution of raw materials and the stages of production of plastic pellets. The environmental burden analyzed includes the production process of recycling plastic waste to produce an output in the form of 1 ton of plastic where the total GHG emissions generated are $2.36E + 03$ kg CO² eq, with details of the potential contribution to global warming of $1.30E + 02$ kg CO² eq at the stage enumeration, $3.52E + 01$ kg CO² eq at the distribution stage and $2.15E + 00$ kg CO² eq at the plastic pellets production stage. The efficiency of plastic seed products in this study showed a good result, where the NEV and NER values of the recycled plastic pellets products were 39664.1 MJ and 2.11 MJ.

Keywords. Recycling, plastic waste, GHG emissions, efficiency energy, LCA

1. Introduction

The high use of plastic products is currently causing uncontrolled accumulation of plastic waste so that an effort is needed to minimize the negative impacts caused to the environment. One of the appropriate efforts in processing plastic waste is recycling to

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produce a variety of useful products. Widely, recycling is considered to have a positive impact for the environment and effective for sustainable development, which can reduce limited resources, reduce demand of landfill and can save energy consumption. However, in every process such as collecting and sorting materials for recycling have own environmental impact, including the energy used and the impact of energy use in the manufacturing process of new products [2]. The recycling process in relation to energy savings has a different value depending on the type of material to be recycled [3]. Each stage of the process in managing plastic waste recycling starts from collecting raw materials to producing a new product for consumers requiring energy that can be calculated and analyzed for their impact on the environment using the LCA method.

Life Cycle Assessment is one of the decision makers of a waste management strategy that considers environmental aspects as the main concern and is an approach that studies the potential impact of products or systems from raw material extraction to production, use and disposal [1]. The use of the LCA method is very useful for knowing complete data, evaluating, and review all the environmental impacts associated with products, processes and activities.

In the waste management sector, LCA calculations can effectively measure the dynamic flow of resources and can provide important information regarding the environmental burden of waste generated, through the LCA approach it can also be seen that the recycling process in waste management uses the most energy efficient [6, 7].

There are currently several studies on the assessment of environmental impacts on the use of plastics and plastic recycling using the Life Cycle Assessment approach, such as research on environmental impact analysis on plastic bag waste and industry of plastic waste recycling [10, 11]. In general, recycled plastics can be considered a source of renewable raw materials and their use in the manufacturing industry sector can reduce greenhouse gas (GHG) emissions and carbon footprint [5, 13]. Besides having a positive impact on the environment, recycling also provides economic benefits because it can save around 20-50% of the price of raw materials on the market when compared to raw materials [8].

Based on the results of research by Hendrawan (2010) it is known that in conventional plastic recycling systems, the manufacturing sector contributes higher CO₂ emissions by 93.6% compared to the transportation sector which is only 6.4%. Thus, an environmental impact study of the process of recycling plastic waste using the LCA method is very necessary to find out information on the development of the plastic waste recycling industry comprehensively by calculating and analyzing the emission value generated at each stage of the production process and aims to evaluate and provide opportunities in implementing possible environmental improvements.

2. Research methodology

Analysis of the data in this study is used the LCA procedure according to ISO 14040 (2016) which consists of four phases, namely system boundary and functional unit, inventory analysis, impact analysis, and interpretation.

2.1 System boundary and functional unit

The purpose of this LCA study is to evaluate the environmental performance of each plastic waste recycling route in the industrial plastic pellets and calculates the contribution of each process to the total environmental impact of the recycling route by identifying the main processes, while the LCA boundaries of the production process are:

- Assessment of the LCA conducted on material utilization of water, energy and emissions produced.
- Assessment of LCA refers to the concept of cradle to gate, where the analysis is limited to the production phase starting from plastic waste collection process to produce a new product.
- Functional unit is 1 tonne of plastic resin that are the result of recycling HDPE plastic waste.

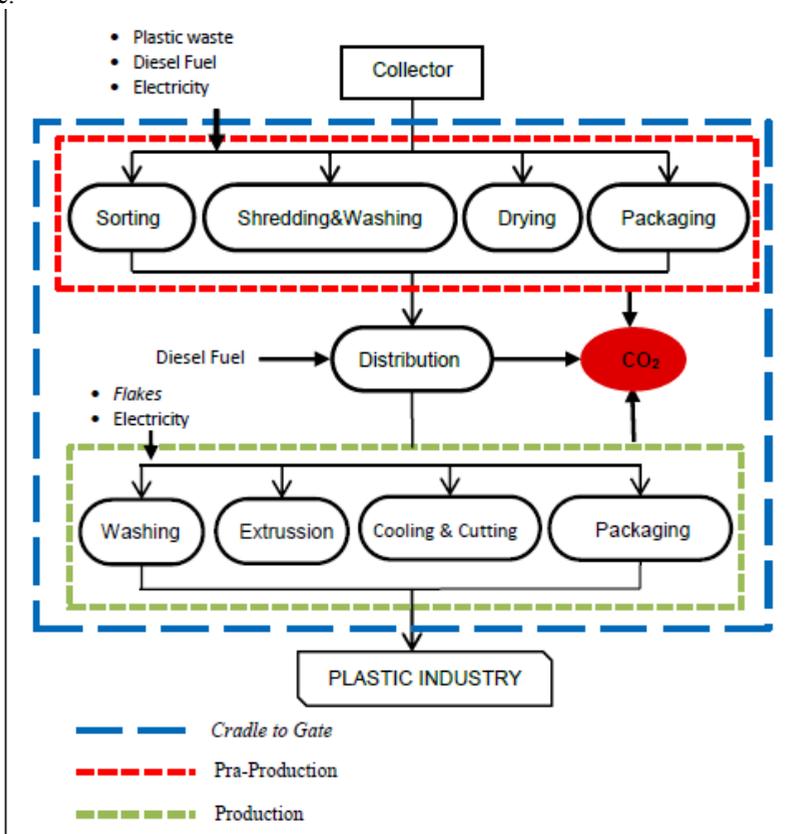


Fig.1 Flowchart Boundaries Plastic Waste Recycling System

2.2 Life Cycle Inventory

Inventory analysis describes the flow of material and energy that is involved in plastic waste recycling. Data collection from energy inputs in the form of water use, energy distribution and fuel use is calculated quantitatively. Calculation of estimated net energy is the energy conversion in the form of standard energy units (Joules), then for the calculation of the energy needed from each production of 1 tonne of plastic resin refers to the equation by KLH (2012a) or IPCC (2006).

$$E_n = n \times CV \tag{1}$$

Where:

- E_n = Energy
- n = Inventory volume
- CV = Calorific Value

1. Diesel fuel

The analytical method used to estimate the energy consumption of diesel fuel is the conversion of fuel usage to a standard energy unit (Joule). To get the number of energy consumption in each production of 1 ton of plastic pellets, the calculation is:

$$Total\ EC\ \left(\frac{MJ}{ton}\right) = \frac{EC \times CV}{Total\ Production(Ton)} \quad (2)$$

Where:

EC = Energy Consumption

CV = Calorific Value

2. Electricity

According to Susanta and Sutjahjo (2007), greenhouse gas emissions from electricity usage are generated by burning coal or geothermal fuel (fossil fuels) in power plants. Pollutants produced include CO₂, SO₂, and NO_x which can cause acid rain. Electricity consumption does not directly contribute to CO₂ emissions, but it does contribute to produce CO₂ at the center of power plants that are fossil fuel.

$$EF = SFC \times NCV \times CEF \times Oxid \times 44/12 \quad (3)$$

Where:

EF = Emission factor

SFC = Specific Fuel Consumption (kt fuel/MWh)

NCV= Net Calorific Value (TJ/kton fuel))

CEF = Carbon Emission Factor (TC/TJ)

Oxid= Oxidation factor

3. Energy Efficiency

Energy efficiency is expressed in terms of Net Energy Value (NEV) and Net Energy Ratio (NER). NER and NEV calculations are:

$$NEV = \sum Eno - \sum Eni \quad (4)$$

$$NER = \sum Eno / \sum Eni \quad (5)$$

Where:

NEV= Net Energy Value

NER= Net Energy Ratio

ΣEno= Total energy output

ΣEni= Total energy input

The net energy performance which is quite good from the product life cycle is indicated by the NEV value which is positive and the NER is above 1.

2.3 Life Cycle Impact Assessment

This stage is carried out to study or evaluate the environmental impacts generated based on the results of the collection and calculation of the data themselves using several assumptions at the inventory analysis stage. The grouping of environmental impacts caused by the plastic waste recycling industry activities in this study only focuses on the impact on greenhouse gases (global warming). The method of calculating the amount of potential GHG emissions from each energy use refers to the equation delivered by KLH (2012a).

$$GHG\ Emission\ \left(\frac{kg}{yr}\right) = EC\ \left(\frac{TJ}{yr}\right) \times Emission\ Factor\ \left(\frac{kg}{TJ}\right) \quad (6)$$

The diversity of gas generation (such as CO₂, N₂O, SO₂, etc.) makes research to convert the value of identified gases (IPCC, 2006). This conversion activity is carried out in

order to get the CO₂ equivalent value of each identified gas. The conversion value used is the value derived from the climate change connection (2016) database whose overall values are listed in **Table 1**.

Table 1. CO₂ Equivalent GHG Conversion Value [4]

Greenhouse Gas	Formula	100-year GWP
Carbon Dioxide	CO ₂	1
Methane	CH ₄	25
Nitrous Oxide	N ₂ O	298
Sulphur Hexafluoride	SF ₆	22.800
Hydrofluorocarbon-23	CHF ₃	14.800
Hydrofluorocarbon-32	CH ₂ F ₂	675
Perfluoromethane	CF ₄	7.390
Perfluoroethane	C ₂ F ₆	12.200
Perfluoropropane	C ₃ F ₈	8.830
Perfluorobutane	C ₄ F ₁₀	8.860
Perfluorocyclobutane	c-C ₄ F ₈	10.300
Perfluoropentane	C ₅ F ₁₂	13.300
Perfluorohexane	C ₆ F ₁₄	9.300

2.4 Interpretation

The final stage in the LCA is to interpret the results, evaluate, and analyze the efforts that can be made in order to improve products, processes, and reduce environmental impact. Improvement of product life cycle would have to produce the product life cycle that increases positively from energy efficiency and can reduce GHG emissions. The results of the analysis that have been carried out during the inventory and impact assessment stages are manifested in actions that will benefit the industry and the environment.

3. Result and Discussion

3.1 Data Inventory

Inventory data in the processing of plastic waste recycling is obtained from primary data observation and LCI database based on functional unit, which is 1 ton of plastic pellets.

Data includes the input of raw materials and energy as well as the output of main products are plastic pellets and emissions at each stage of the process. These data are presented quantitatively by showing the number of inputs and outputs to the system and qualitatively consisting of components the input of environmental impact parameters. After observations for data collection, all required inputs are obtained at each stage of the plastic waste recycling process. Details of the analysis data inventory in the process of recycling plastic waste can be seen in Table 2.

Table 2. Mass Balance of Plastic Waste Recycling Process

Input		Production Stage	Output	
Plastic Waste	40.866 kg	Shredding	Flakes	32.693 kg
Water	72.000 litre		Bottle cap	6945 kg
Diesel energy	1438.67 MJ		Plastic sheet	1228 kg
Electricity	4.33 Kwh		Water	72000 litre
			Energy	1.966,8 MJ
Diesel fuel	1343,04 litre	Distribution		
Petrol	20,38 litre		Energy	569,1 MJ
Flakes	192.327 kg	Manufacture	Plastic	186.557 kg
Water	3.600.000 litre		Pellets	3.600.000
Electricity	3071,79 Kwh		Water	litre
			Energy	33.200 MJ

3.2 Life Cycle Impact Assessment

3.2.1 The Potential of Global Warming

The results of the life cycle global warming potential include the impact of process emissions, emissions from extraction, processing and combustion of fuels used for energy and transport processes. In this study, the total emission that has the potential for global warming is calculated using Simapro 8.4 Faculty Version is $2.36E+03$ kg CO₂ eq. At the stage of shredding, the total contribution of the potential for global warming is $1.30E+02$ kg CO₂ eq, where the use of diesel fuel as an energy dominates at $1.27E+02$ kg CO₂ eq. At the stage of distribution of total GHG emissions is $3.52E+01$ kg CO₂ eq and at the production stage of plastic pellets produces GHG emissions of $2.15E+00$ kg CO₂ eq which is dominated by the use of electrical energy in the production machine. For more details of GHG emissions caused at each stage of the process recycling plastic waste to produce products of plastic pellets can be seen in **Table 3**.

Table 3. Global Warming Potential at each stage Process

Stages	Environmental Impact			
	Fossil CO ₂ eq	Biogenic CO ₂ eq	CO ₂ eq from land transformation	CO ₂ Uptake
Shredding	1.30E+02	1.84E-01	9.05E-03	1.89E-01
Distribution	3.61E+01	2.81E-01	1.53E-02	3.00E-01
Manufactur	2.18E+03	4.60E+00	2.26E-01	4.78E+00
Total	2.36E+03			

The difference in energy use at each stage of the production process of plastic waste recycling has resulted environmental impact differently. It can be seen in **Figure 2** where the stages of plastic pellets production contributed the most all impacts in this research. This is influenced by the use of electrical energy in all equipment / machinery used in the plastic pellets production process.

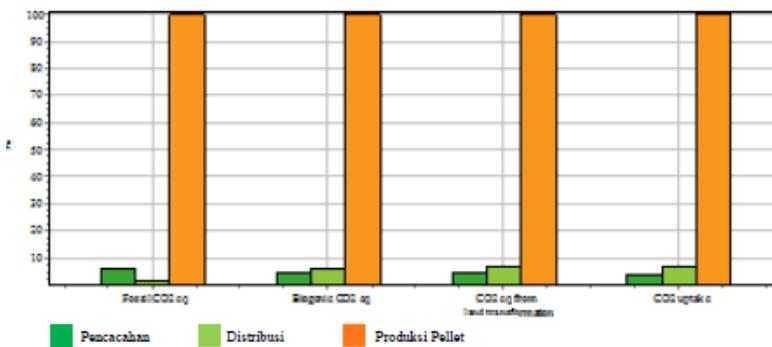


Fig. 2. Potential of global warming comparison

3.2.2 Energy Efficiency

Energy efficiency in this LCA study can be determined by measuring the net energy of plastic pellets product life cycle. Energy inputs such as fuel for diesel engine, transportation (petrol and diesel) are required as well as the use of electricity from production equipment. The output of plastic pellets which certainly has its own heating value. Data from these calculations and NEV and NER values can be seen in Table.4.

The biggest energy input comes from the use of electrical energy at the production stage of plastic pellets with a percentage of 92.90%, that is because all production activities use tools or machines that are driven by electrical energy.

NEV and NER values from the plastic waste recycling process have shown good results, where energy efficiency in the life cycle of a product is said to be good if it has a positive NEV value and has a NER value of more than 1 [14]. Each NEV and NER value of the recycled plastic pellets product is 39664.1 and 2.11 MJ / Ton of plastic pellets.

Table 4. Total Input-Output Energy, NER and NEV per Ton Plastic Pellets

Input Energi	Besaran Energi	
	MJ/ton Pellet	Persentase (%)
Shredding		
Diesel Fuel	1920	5.37%
Electricity	46.8	0.06%
Distribution		
Diesel Fuel	497.5	1.39%
Petrol	71.6	0.20%
Manufacture		
Electricity	33200	92.90%
Total Input Energy	35735.9	100%
Output Energy	75400	
Net Energy Value (NEV)	39664.1	
Net Energy Ratio (NER)	2.11	

4. Conclusion

The conclusion from the study of Life Cycle Assessment (LCA) in the production process of recycled plastic pellets, where the environmental burden analyzed includes the production process of recycling plastic waste to produce an output of 1 ton plastic pellets and the potential for global warming which results in a total is $2.36E + 03$ kg CO₂ eq. In the shredding stage, the total contribution of the potential for global warming is $1.30E + 02$ kg CO₂ eq, where the use of diesel fuel as a diesel energy dominates at $1.27E + 02$ kg CO₂ eq. At the stage of distribution of total GHG emissions caused by $3.52E + 01$ kg CO₂ eq and at the production stage of plastic pellets produces GHG emissions of $2.15E + 00$ kg CO₂ eq which is dominated by the use of electrical energy as the prime mover in production machine. And the efficiency of plastic pellets products in this study showed a good results, where the NEV and NER values of the recycled plastic seed products were 39664.1 MJ and 2.11 MJ.

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