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Environmental Impact Analysis Using *Life Cycle Assessment* (LCA) on Plastic Waste Processing at Antang Makassar Landfill

Amrul [1], Nurul Chairany [2*], Andi Pawennari [3]
[1,2,3*] Industrial Engineering Study Program, Faculty of Industrial Technology, Universitas Muslim Indonesia

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*Corresponding Author

Name : Nurul Chairany
E-mail: nurul.chairany@umi.ac.id

ABSTRACT

This study analyzes emission loads generated from plastic waste shredding activities around the Antang Landfill. The process involves the use of transportation vehicles, diesel engines, polypropylene sacks, and polyethylene terephthalate (PET) packaging from used cooking oil containers. Diesel combustion and transportation activities contribute to air pollution, while shredded plastic waste may release additional emissions into the environment. The research aims to evaluate the environmental impacts of plastic waste shredding and propose strategies for sustainable waste management. The Life Cycle Assessment (LCA) method was applied to assess environmental aspects and potential impacts through input–output inventory analysis. Data were processed using SimaPro software, with impact assessment conducted through categorization and normalization stages. The findings reveal three main impact categories: global warming, ozone layer depletion, and human toxicity. The collection stage contributes most to human toxicity (4.66E-5 and 2.48E-16), while the transportation stage produces the highest emissions from operational vehicles (8.12E-5 and 4.32E-16). During the shredding stage, diesel combustion contributes most to ozone layer depletion (1.02E-8) and human toxicity (2.52E-13). The plastic fragment handling stage shows significant impacts on ozone layer depletion (7.9E-9) and global warming (8.69E-13). Further research is recommended to develop emission reduction strategies that integrate cost efficiency and stakeholder participation.

INTRODUCTION

The problem of waste has become a critical global issue that threatens environmental sustainability and public health. Rapid population growth, urbanization, and increasing income levels have led to more consumptive lifestyles, resulting in higher rates of waste generation worldwide [1]. Among various types of waste, plastic waste has drawn particular attention due to its persistence, non-biodegradable properties, and complex recycling challenges. Global plastic production now exceeds 400 million tons annually, with a significant proportion ending up in landfills or entering marine environments [2], [3]

In Indonesia, the challenge of waste management is increasingly urgent. National waste generation has reached approximately 38 million tons per year, of which around 30% is plastic waste [4]. This number continues to grow as consumer demand for packaged goods rises. Plastic packaging dominates national plastic use, accounting for 65% of total plastic consumption, while the food and beverage industry contributes about 60% of that packaging waste [5]. This pattern demonstrates the strong correlation between economic development, consumer behavior, and the rapid increase in plastic waste. Plastic waste pollution presents serious environmental and ecological hazards, particularly to marine ecosystems. Plastics that enter the ocean can injure marine species or be ingested, leading to digestive blockage, starvation, and death [6]. Microplastic contamination has emerged as an alarming concern, with studies reporting 10–20 microplastic particles per kilogram of salt, suggesting the infiltration of plastics into daily human consumption [7]. The highest concentrations of microplastic pollution in Indonesia have been recorded along the coasts of Jakarta and South Sulawesi, ranging from 7.5–10 particles per cubic meter [8]. Moreover, research conducted in Makassar and Bitung found that 58–89% of fish species contained microplastics, indicating significant bioaccumulation and potential health risks for humans through seafood intake [9].

Antang Final Disposal Site (TPA) in Makassar represents one of the major solid waste management challenges in eastern Indonesia. Covering an area of 20.8 hectares, the site has exceeded its capacity, with waste piles reaching heights of up to 50 meters. Frequent spontaneous fires, triggered by methane accumulation and unmanaged decomposition, further degrade air quality and threaten nearby communities [10]. The waste growth rate in the area is estimated at 11.53% per year, emphasizing the urgent need for improved management strategies [10]. Among the dominant types of waste found in Antang TPA, refill plastic packaging waste is particularly prevalent. This type of packaging is widely used in food processing and household consumption, especially for cooking oil stored in polyethylene terephthalate (PET) containers, which are preferred for their convenience and product quality preservation [5, 11]. However, improper disposal of these materials contributes substantially to environmental pollution and greenhouse gas emissions.

Plastic waste management practices in the area generally involve sorting, transportation, and shredding, relying heavily on diesel-powered engines and small-scale vehicles. While these operations play a role in recycling, they also generate secondary environmental impacts, including air emissions, greenhouse gas output, and particulate pollution from diesel combustion [12, 13]. Despite these challenges, research on emission loads from plastic waste shredding processes in Indonesia remains limited. Therefore, this study aims to analyze the emission load produced by plastic waste shredding activities around the Antang TPA using the Life Cycle Assessment (LCA) framework. The assessment focuses on key environmental impact categories such as global warming potential, ozone layer depletion, and human toxicity by evaluating emissions from each stage of plastic waste processing. The findings are expected to support the formulation of sustainable waste management strategies and inform policy interventions aimed at reducing environmental burdens from plastic waste in Indonesia [13].

Therefore, this study aims to analyze the emission load produced by plastic waste shredding activities around the Antang TPA using the Life Cycle Assessment (LCA) framework. The assessment focuses on key environmental impact categories—global warming potential, ozone layer depletion, and human toxicity—by evaluating emissions from each stage of plastic waste processing. The findings are expected to support the formulation of sustainable waste management strategies and inform policy interventions aimed at reducing environmental burdens from plastic waste in Indonesia [14].

RESEARCH METHODS

1. Life Cycle Assesment

This study employs the Life Cycle Assessment (LCA) method to evaluate the environmental aspects and potential impacts arising from plastic waste shredding activities around Antang Final Disposal Site. The respondents of this study were plastic waste processing factory and waste disposal site manager. LCA is an internationally recognized analytical tool based on the ISO 14040 and ISO 14044 standards, which enables the systematic evaluation of environmental burdens associated with a product, process, or service throughout its life cycle from raw material acquisition to end-of-life management [12, 14]. In this research, LCA is used to quantify the environmental performance of plastic waste processing operations, particularly focusing on emission loads generated during the collection, transportation, shredding, and handling stages.

The implementation of LCA in this study follows four main stages: (1) goal and scope definition, (2) life cycle inventory (LCI), (3) life cycle impact assessment (LCIA), and (4) interpretation [15].

1. **Goal and Scope Definition**. The goal of this study is to assess the environmental impacts of the plastic waste shredding process and identify the main sources of emissions contributing to global warming, ozone layer depletion, and human toxicity. The functional unit used is one ton of processed plastic waste, which serves as a reference for quantifying inputs and outputs. The system boundary is defined as "gate-to-gate," covering the stages of plastic waste collection, transportation, shredding, and fragment handling within the Antang TPA area.
2. **Life Cycle Inventory (LCI)**. The LCI stage involves the systematic collection and quantification of data related to energy use, material inputs, fuel consumption, and emission outputs. Primary data were obtained through direct field observations and interviews with operators involved in the plastic shredding process, while secondary data were collected from previous studies, government reports, and emission factor databases. Input data include diesel fuel consumption for transport and machinery operations, while output data cover air emissions such as CO_2, NO_x, SO_2, and particulate matter.
3. **Life Cycle Impact Assessment (LCIA).** The LCIA was conducted using SimaPro 9.0 software, a widely used platform for environmental impact modeling. The CML-IA baseline method was applied to evaluate environmental impact categories. Impact assessment was performed through categorization (classifying results into impact categories) and normalization (comparing relative significance across categories). The key impact indicators analyzed include Global Warming Potential (GWP), Ozone Layer Depletion Potential (ODP), and Human Toxicity Potential (HTP).
4. **Interpretation.** The final stage involves interpreting results to identify critical processes contributing to emissions and recommending mitigation strategies for improving the environmental performance of plastic waste shredding operations. Sensitivity analysis was also performed to validate the robustness of the results and to ensure alignment with ISO-based methodological requirements.

2. Process Mapping

To identify the plastic waste processing flow, a process map is needed to obtain information on each stage of the process. This analysis uses the 5M+E: Man, Machine, Method, Material, Measurement, and Information as shown in Table 1.

Table 1. Process Mapping

	Description	**Process Analysis Using 5M+E**
Waste Collection	The waste collection process starts from the Antang Makassar landfill, which is carried out by collectors.	1. Using conventional methods/without using tools 2. The material collected is plastic waste 3. The plastic waste is placed in polypropylene sacks

Transportation	The process of sending plastic waste to the factory using a pick-up truck	1. Delivery using a pickup truck 2. Plastic waste is stored in polypropylene sacks 3. Delivery takes 15-20 minutes
Sorting	Sorting in this case is separation based on the color of the packaging by taking the refill cooking oil packaging.	1. Sorting is done manually/directly by human hands 2. Sorting is done by factory employees
Plastic waste shredding	The plastic waste from refilled cooking oil packaging enters the shredding machine through the funnel at the top of the diesel engine.	1. Using a diesel engine that runs on diesel fuel
Taking the shred waste	The shred waste results go into a water-filled storage tank.	1. The shred results are collected using a plastic basket. 2. The chopped results are then placed into polypropylene sacks.

To understand the inputs, processes, and outputs at each stage of plastic waste processing, a mapping process is necessary. The mapping process also serves to identify limitations in research focused on identifying and calculating the potential environmental impacts of the plastic waste processing process as shown in Fig.1.

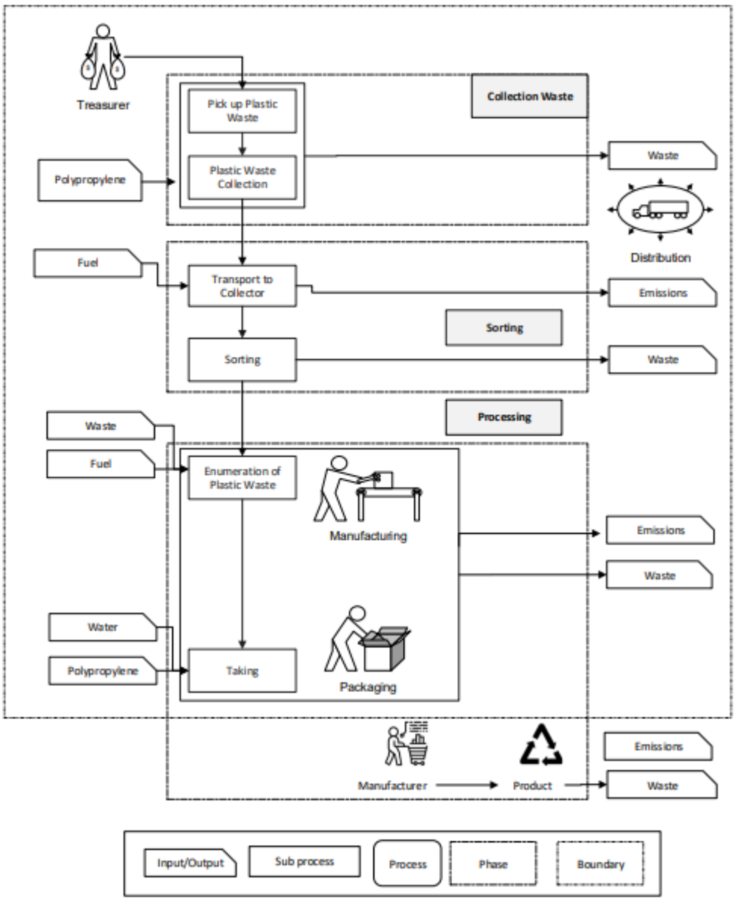

Fig. 1. Plastic Waste Processing Process

RESULTS AND DISCUSSION

1. Environmental Impact on the Plastic Waste Collection Process

The environmental impacts resulting from the process of collecting plastic waste using categorization can be seen in the following table, which shows that human toxicity is the highest impact category, namely 4.66E-5 which comes from the use of polypropylene.

Table 2. Environmental Impact of the Plastic Waste Collection Process Using *Categorization*

Impact Category	Units	Total	Polypropylene, Granulate	Polyethylene Terephthelate
Global Warming (GWP100)	Kg CO2 eq	-2.41	0.00372	-2.41
Ozone Layer Depletion (ODP)	Kg CFC=11 eq	-1.15E-7	1.99E-13	-1.15E-7
Human Toxicity	Kg 1.4=DB eq	-0.587	4.66E-5	-0.587

Meanwhile, for normalization, the results of data processing show that the highest impact category is human toxicity of 2.48E-16 which comes from polypropylene, we can see the results in the following table.

Table 3. Environmental Impact of the Plastic Waste Collection Process Using Normalization

Impact Category	Units	Total	Polypropylene, Granulate	Polyethylene Terephthelate
Global Warming (GWP100)	Kg CO2 eq	-1.05E-11	1.47E-14	-1.05E-11
Ozone Layer Depletion (ODP)	Kg CFC=11 eq	-1.18E-13	2.03E-19	-1.18E-13
Human Toxicity	Kg 1.4=DB eq	-3.12E-12	2.48E-16	-3.12E-12

In the waste collection stage, polypropylene granulate was identified as the dominant contributor to environmental impacts. Based on categorization, the human toxicity impact reached 4.66E-5, which was significantly higher than other impact categories such as global warming (0.00372) and ozone layer depletion (1.99E-13). This result indicates that emissions released during the handling of polypropylene granules was possibly from dust and microplastic exposure was pose potential health risks to workers and nearby communities. The normalization results reinforced this finding, where polypropylene granulate remained the highest contributor with values of 1.47E-14 for global warming, 2.03E-19 for ozone depletion, and 2.48E-16 for human toxicity.

2. Environmental Impact on the Plastic Waste Transportation Process

In the process of transporting plastic waste using categorization, the results of data processing show that human toxicity is the largest impact category, namely 8.12E-5 on the operation/passenger car impact indicator.

Table 4. Savings Matrix

Impact Category	Units	Total	Plastic Waste	Operation, Passenger Car
Global Warming (GWP100)	Kg CO2 eq	-0.00378	-0.00503	0.00125
Ozone Layer Depletion (ODP)	Kg CFC-11 eq	-2.93E-11	-2.19E-10	1.89E-10
Human Toxicity	Kg 1.4-DB eq	-0.00103	-0.00111	8.12E-5

In the transportation process using normalization, the results of data processing which is the largest contributor to emissions is the operation/passenger car amounting to 4.32E-16 for human toxicity.

Table 5. Environmental Impact of the Plastic Waste Collection Process Using Normalization

Impact Category	Units	Total	Plastic Waste	Operation, Passenger Car
Global Warming (GWP100)	Kg CO2 eq	-1.5E-14	-0.00457	0.00125
Ozone Layer Depletion (ODP)	Kg CFC-11 eq	-2.99E-17	-2.23E-16	1.93E-16
Human Toxicity	Kg 1.4-DB eq	-5.49E-15	-5.92E-15	4.32E-16

During the transportation stage, operation/passenger cars emerged as the main emission sources. Categorization results show that human toxicity recorded the highest impact at 8.12E-5, followed by global warming (0.00125) and ozone layer depletion (1.89E-10). These results suggest that the combustion of fossil fuels in transportation vehicles contributes substantially to both local air pollutants and greenhouse gas emissions. The normalization data further confirmed this, showing human toxicity (4.32E-16) as the largest impact category, followed by global warming (0.00125) and ozone depletion (1.93E-16). Thus, the transportation of plastic waste represents a critical stage that demands emission control interventions, such as fuel efficiency improvements or alternative energy use.

3. Environmental Impact on the Plastic Waste Shredding Process

The process of enumerating plastic waste uses categorization, the results of the data processing carried out show that the use of diesel engines is the biggest cause of ozone layer depletion of 1.02E-

Table 6. Environmental Impact of the Process of Enumerating Plastic Waste Using *Categorization*

Impact Category	Unit	Total	Transported Plastic Waste	Diesel, Burned in Chopper/RER U
Global Warming (GWP100)	Kg CO2 eq	0,0741	-0,00379	0,0779
Ozone Layer Depletion (ODP)	Kg CFC-11 eq	1,02E-8	-2,94E-11	1,02E-8
Human Toxicity	Kg 1,4-DB eq	0,0463	-0,00103	0,0473

The results of data processing using normalization in the plastic waste counting process show that the use of diesel engines triggers global warming with a value of 3.09E-13.

Table 7. Environmental Impact of the Process of Shredding Plastic Waste Using Normalization

Impact Category	Units	Total	Transported Plastic Waste	Diesel, Burned in Chopper/RER U
Global Warming (GWP100)	Kg CO2 eq	2.94E-13	-1.5E-14	3.09E-13
Ozone Layer Depletion (ODP)	Kg CFC-11 eq	1.04E-14	-3E-17	1.04E-14
Human Toxicity	Kg 1.4-DB eq	2.46E-13	-5.5E-15	2.52E-13

In the shredding stage, diesel burned in chopper machines was identified as the primary emission source. Based on categorization, the highest impact was observed in ozone layer depletion (1.02E-8), followed by global warming (0.0779) and human toxicity (0.0473). The combustion of diesel fuel releases nitrogen oxides (NOx) and particulate matter, which contribute to both ozone layer damage and respiratory toxicity. Normalization results also showed high impact values, 3.09E-13 for global warming, 1.04E-14 for ozone depletion, and 2.52E-13 for human toxicity that indicating that the shredding stage is a major hotspot in the system.

4. Environmental Impact on the Plastic Waste Collection Process

The process of taking plastic fragments using categorization from the data processing results shows that transported plastic waste has the largest contribution to the ozone layer depletion impact category of 7.9E-9. We can see this in the following data processing results table.

Table 8. Environmental Impact of the Process of Collecting Chopped Plastic Waste Using *Categorization*

Impact Category	Unit	Total	Transported Plastic Waste	Tap Water, at User/CH U	Polypropylene Injection
Global Warming (GWP100)	Kg CO2 eq	0,294	0,0741	0,000154	0,219
Ozone Layer Depletion (ODP)	Kg CFC-11 eq	1,02E-8	7,9E-9	1,5E-11	x
Human Toxicity	Kg 1,4-DB eq	0,0473	0,0463	2,37E-5	0,00097

In the plastic waste collection process using *normalization*, the biggest impact indicator is polypropylene injection with the impact category being global warming of 8.69E-13.

Table 9. Environmental Impact on the Process of Shredding Plastic Waste Using Normalization

Impact Category	Units	Total	Transported Plastic Waste	Tap Water, at User/CH U	Polypropylene Injection
Global Warming (GWP100)	Kg CO2 eq	1.16E-12	2.94E-13	6.12E-16	8.69E-13
Ozone Layer Depletion (ODP)	Kg CFC-11 eq	1.04E-14	1.04E-14	1.53E-17	x
Human Toxicity	Kg 1.4-DB eq	2.51E-13	2.46E-13	1.26E-16	5.16E-15

In the plastic fragment collection process, transported plastic waste was identified as the largest contributor to ozone layer depletion (7.9E-9). Another significant contributor was tap water, particularly in the human toxicity (2.37E-5) and ozone layer depletion (1.5E-11) categories. This implies that the water used during washing or handling may contain dissolved microplastics or residues that contribute to environmental stress. Under normalization, the global warming potential was distributed across transported plastic waste (2.94E-23), tap water (6.12E-16), and polypropylene injection (8.69E-13). For human toxicity, these same indicators contributed 2.46E-13, 1.26E-16, and 5.16E-15, respectively.

The findings of this study are consistent with previous LCA-based research emphasizing the significant contribution of fuel consumption and material transport to environmental impacts in plastic waste management. According to Fatimah, et al. [14] and Schwarz, et al. [16], transportation and energy-intensive processes are the largest sources of greenhouse gas emissions and human toxicity within the plastic recycling chain. Similarly, Neo, et al. [13] observed that diesel combustion during mechanical recycling contributes strongly to ozone layer depletion and respiratory effects due to particulate matter emissions. The dominance of human toxicity and global warming categories in this study aligns with

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the results reported by Rochman, et al. [9], who identified these impacts as critical in evaluating the sustainability of plastic waste treatment systems. This study thus reinforces the global consensus that optimizing energy use and adopting low-emission transportation strategies are essential for reducing the environmental footprint of waste management. It also extends previous work by providing a localized perspective from the Antang region, emphasizing the urgent need for integrating renewable energy sources and closed-loop recycling technologies to achieve a more sustainable plastic waste management system.

CONCLUSION

This study applied the Life Cycle Assessment (LCA) method to evaluate emission loads from the plastic waste shredding process around the Antang landfill area. The results identified three main environmental impact categories: global warming, ozone layer depletion, and human toxicity. Among these, human toxicity showed the highest impact, particularly during the collection and transportation stages, with emissions largely resulting from vehicle operations and material handling. The shredding stage, driven by diesel fuel combustion, contributed significantly to both ozone layer depletion and human toxicity, while the fragment collection process increased the impacts of global warming and ozone depletion. Overall, the findings indicate that fuel-based activities, especially transportation and shredding, are the main sources of environmental burden. Reducing diesel dependency and optimizing logistics efficiency are essential to minimize emissions and improve the sustainability of plastic waste management processes. to emissions from operational vehicles, which reached 8.12E-5 and 4.32E-16 in the same categories.

Future research should extend the assessment to include upstream and downstream processes, such as recycling, reuse, or regranulation, to achieve a more comprehensive cradle-to-grave evaluation. Investigating the adoption of renewable energy sources. Comparative LCA studies across different waste treatment technologies (e.g., mechanical recycling, pyrolysis, or chemical depolymerization) are also recommended to inform sustainable waste management policies and emission mitigation strategies in Indonesia.

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