Analysis of Global Warming Potential (GWP) in Waste Transportation System Using Life Cycle Assessment Method in Panakkukang District, Makassar City

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ABSTRACT

Global warming is an ecosystem imbalance caused by an increase in atmospheric temperature mainly caused by the Greenhouse Gas effect. Global warming potential (GWP) is caused by several human activities, one of which is waste management. This study aims to analyze the environmental impact, especially on the amount of GWP in the waste transportation system in Panakkukang sub-district, Makassar using the Life Cycle Assessment method of Simapro software version 9.5. The research stages by analyzing the transportation route that has been applied and then comparing it with the scenario route as an alternative route on the type of arm roll truck vehicle. The research shows in general that the existing route is the shortest transportation route with the smallest GWP impact. The amount of GWP for the entire waste transportation route in the Panakkukang sub-district, Makassar is 1,352, 64 kg CO2 eq.

Keywords: waste transportation; global warming potential; life cycle assessment; Panakkukang.

INTRODUCTION

Global warming is an ecosystem imbalance caused by an increase in atmospheric temperature, mainly due to the effects of Greenhouse Gases (GHG). This is what significantly traps infrared radiation heat in the atmosphere. The Intergovernmental Panel on Climate Change (IPCC) states that if we do not prevent and address GHG emissions, the earth's temperature will increase by 6.4 ° C (Kristanto, et al., 2019).

The potential for global warming or Global Warming Potential (GWK) is caused by several human activities, one of which is waste management. Waste management produces the potential for global warming, both from the transportation and processing processes related to materials, energy needs and sampling results from the entire process. The environmental impact of waste management is often not considered. This will affect the implementation of regulations to manage waste holistically. In the waste management system, waste transportation is a waste management sub-system that is still a problem and needs special attention. Waste transportation aims to carry waste from the waste source to the final processing site. By optimizing this sub-system, the most optimum transportation route will be obtained so that it is expected that in addition to a much more efficient management system in terms of operations and costs, it can also provide a more minimal environmental impact. Life Cycle Assessment (LCA) is generally a method that analyzes the environmental burden at all stages in the life cycle of a product starting from resource extraction, through the production process of materials, product parts, and use until the product is disposed of as waste (either reuse, recycling or final disposal). LCA produces a holistic approach that aims to quantify the potential environmental impacts (climate change, use of non-renewable energy, etc.) resulting from the product cycle above. Therefore, Simapro software is used which can collect, analyze and monitor the product performance environment systematically and transparently according to ISO 14040 standards (Grzesik and Guca, 2011). The purpose of this study is to analyze the level of Global

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Warming Potential (GWP) in the waste transportation system in Panakkukang District, Makassar and compare the results obtained with the scenario route as an alternative route so that a transportation route with the smallest environmental impact is obtained.

Waste selection, or waste segregation, is a vital step toward achieving an environmentally sustainable future. It involves the separation of waste into different categories—typically organic, recyclable, and non-recyclable—at the source, enabling more efficient disposal, recycling, and reuse. By practicing waste selection, communities and individuals can significantly reduce the burden on landfills, decrease pollution, and support the circular economy (Darmayanti NL & Dwipayana AD, 2023; Eka Kartika P et.al, 2022). Creating environmentally friendly waste begins with understanding the types of waste generated and taking responsibility for managing them correctly. Organic waste, such as food scraps and garden waste, can be composted to produce nutrient-rich soil, reducing methane emissions from landfills. Recyclable materials like paper, plastics, glass, and metals should be cleaned and sorted to facilitate proper processing and reuse. Hazardous and non-recyclable waste, such as certain electronics or contaminated materials, require special handling to prevent environmental harm (Gusty S et.al, 2023; Junior AOGM & Diwjendra NKA, 2023).

Public participation plays a crucial role in the success of waste selection programs. Educational campaigns and easy-to-use sorting systems can encourage more people to adopt eco-friendly practices. Governments and local authorities must also support these efforts by providing adequate infrastructure, such as color-coded bins, collection services, and recycling centers. Policies that incentivize waste reduction and recycling further strengthen environmental goals. Environmentally friendly waste management not only conserves natural resources but also minimizes greenhouse gas emissions and promotes public health. When waste is properly sorted and processed, less ends up in incinerators or landfills, which are often sources of toxic pollutants. Instead, more waste can be transformed into valuable resources through composting, recycling, and energy recovery (Syaiful S et.al, 2024).

RESEARCH METHODS

The research method used is qualitative and quantitative descriptive research. Where in qualitative descriptive research, field observations and interviews are conducted so that data is obtained which is then described to show the condition of the existing route from the waste transportation system to the Tamangapa TPA. While quantitative descriptive research produces an assessment of the impacts caused by the data obtained and a comparison between the existing route and the scenario route from the waste transportation system to the Tamangapa TPA. Data collection in this research location is in Panakkukan sub-district, Makassar and the route along the sample point to the Tamangapa TPA, Makassar. Primary data is also obtained from the results of interviews and direct observations in the field. Secondary data is data concerning the general conditions at the research location obtained from literature studies, related institutions or agencies. The primary data and secondary data needed in this study can be seen in table 1.

Table 1. Primary data and secondary data

Primasy Data	Secondary Data
1. The amount of waste taken to the landfill 2. The route taken by the transport vehicle (dump truck) 3. The location and point of waste collection by the armroll truck 4. The distance of the route taken by the transport fleet. 5. The travel time taken by the transport fleet.	1. Number of active waste transport fleets 2. Ritation and collection points for waste containers transported by armroll trucks 3. Routes taken by transport trucks (Dump trucks and Tangkasaki)

Source: Research, 2023

RESULT AND DISCUSSION

The results and discussion In this study, Life Cycle Assessment is used as a development method to evaluate all environmental, social and economic impacts in the decision-making process towards more sustainable products during the product's life cycle. The life cycle of a product includes all stages of the product system, from the acquisition of raw materials or production of natural resources to the disposal of the product at the end of its useful life, including extracting and processing raw materials; manufacturing; distribution; use; reuse; maintenance; recycling; and final disposal (UNEP/SETAC, 2011).

Before assessing the waste transportation route using Life Cycle Assessment (LCA), a route scenario was prepared. The route scenario in this study is a comparison to the existing route that has been implemented so far. One approach used in selecting a route is to consider the time, distance traveled and route conditions during the transportation process such as traffic conditions and roads traveled.

The scenario was created on the armroll truck type of vehicle as a comparison to 1 existing route so that the impact of the Global Warming Potential (GWP) of each scenario can be known. Meanwhile, for the type of dump truck and Tangkasaki vehicles, the analysis was carried out only on the existing route, because the method of transporting waste on dump trucks and Tangkasaki is a running route, where the waste collection system is door to door and takes waste from waste accumulation along the transportation route to the TPA. The waste transportation pattern in Panankkukang sub-district uses the Hauled Container System (HCS) method 1 on armroll truck type vehicles, and uses the stationary Container System (SCS) system on Dump truck and Tangkasaki types of vehicles.

Waste transportation facilities for the type of garbage truck in Panakkukang sub-district, Makassar city consist of 3 types, namely:

1. Dump Truck (open back), in this type of dump truck, waste is transported from waste piles located along the road/transportation route that has been determined on each vehicle to the Tamangapa TPA. The dump truck route is a walking route. The number of Dump truck type vehicles operating in Panakkukang sub-district is 19 units.

Figure 1. Dump truck type waste transport vehicle

2. Armroll Truck

The armroll type of vehicle transports waste containers which are communal waste collection points. This truck carries waste from the container point and then takes it to the Tamangapa TPA. The number of armroll truck types operating in Panakkukang sub-district is 13 units.

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Figure 2. Armroll truck type garbage transport vehicle

2. Tangkasaki (closed body)

The Tangkasaki type vehicle is a modification of the closed body truck. This truck is divided into 2 systems, namely the transportation system that picks up garbage along the route and the standby system that receives and carries garbage transported by the 3-wheeled vehicle type used by Panakkukang sub-district to reach garbage accumulations in residential areas that cannot be reached by dump trucks and there are no containers available as communal waste disposal containers. The number of Tangkasaki type vehicles in Panakkukang sub-district is 19 units.

Figure 3. Tangkasaki type waste transport vehicle (closed container)

Implementing Life Cycle Assessment (LCA) in waste transport route evaluation based on PU Regulation No. 3 of 2013. The stages of route assessment using Life Cycle Assessment (LCA) are as follows:

1. Objectives and Scope

The purpose of the impact assessment is to gain a better understanding of the existing system, identify major environmental problems in the product or process life cycle, identify opportunities to improve existing systems, compare systems and their potential impacts, and select options prospectively. Meanwhile, the scope of this impact assessment serves to determine the product or process system to be studied, impact categories, functional units, system functions, system boundaries, allocation procedures, data requirements, and assumption limitations.

2. Data Inventory

In the data inventory stage, all primary and secondary data are collected and analyzed according to the input data needs in the Simapro v.9.5 software used in this study, such as the type of transport vehicle, the weight of the waste transported, the distance traveled by the vehicle from the waste collection point to the Tamangapa TPA. The functional unit used in the inventory analysis stage is the number of tons of waste carried per unit per day. This amount of waste becomes the input data in each alternative that is compiled. Each inputted vehicle needs to enter the vehicle weight value added to the weight of the waste loaded in the distance of the transportation route. This value has a TKM unit (ton km) needed to find the emission value for each route on each vehicle.

3. Impact Assessment

In analyzing the impact on a product, weighting is needed to avoid the possibility of different levels of importance of several LCA category indicators. For example, in a location where eutrophication may not be as much of a problem as human toxicity, a higher weighting factor can be given to human toxicity than eutrophication. By multiplying each indicator by its respective weighing factor, these relative values can be included in the results (Guinée et al., 2002).

The impact assessment in this study used the CML 2 baseline 2000 method, where the CML 2 baseline 2000 method classifies impacts into ten impacts, namely abiotic depletion, acidification, eutrophication, global warming potential, ozone layer depletion, human toxicity, fresh water aquatic ecotoxicity, marine aquatic ecotoxicity, terrestrial ecotoxicity, and photochemical oxidation.

a. Impact Characterization

In this study, the Global Warming Potential (GWP) category is a category selected from the magnitude of the impact that has been classified. Table 2 shows a comparison of the impact characterization results for each transportation route for the Armroll Truck type of vehicle along with the proposed route scenario.

Rute	AT1	AT2	AT3	AT4	AT5	AT6	AT7	AT8	AT9	AT10	AT11	AT12	AT13
Eksisting	13.1	19.9	19.3	16	28.5	21.5	16.9	17.9	11.9	20.7	19.3	20.8	12.8
skenario 1	16.3	20.6	20.2	16.9	26.2	21.9	14.9	18.5	13.9	21.4	24.3	19.9	14.6
skenario 2	15.3	23.8	19.3		26.2	24.1	14.3				19.3	19.9	

Figure 4. Comparison of GWP for Armroll Truck type waste transportation routes (Kg CO2 eq)

In the following figure 5, you can see a comparison of the impact characterization results for each transportation route for the Dump Truck type of vehicle.

Dump Truck	DT1	DT2	DT3	DT4	DT5	DT6	DT7	DT8	DT9	DT10
	35.3	35.8	22.6	28.1	31.3	33	45.9	47.5	24.7	29.9
	DT11	DT12	DT13	DT14	DT15	DT16	DT17	DT18	DT19	
	31.5	29.3	24	32	19	30	27.4	24.4	59.4	

Figure 5. Comparison of GWP for Dump Truck type waste transportation routes (Kg CO2 eq)

Meanwhile, for Tangkasaki type vehicles, a comparison of the impact characterization results for each transportation route can be seen in figure 6 below.

TANGKASAKI	TK1	TK2	TK3	TK4	TK5	TK6	TK7	TK8	TK9	TK10
	54.2	27.3	22.1	21.6	16.8	27.3	29.1	23.5	20.4	18.9
	TK11	TK12	TK13	TK14	TK15	TK16	TK17	TK18	TK19	
	31.9	29	24.9	27.6	23.4	22.9	26.44	23.4	32.2	

Figure 6. Comparison of GWP for Tangkasaki type waste transportation routes (Kg CO2 eq)

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Interpretation (Life Cycle Impact Interpretation)

Interpretation is the final stage in the Life Cycle Assessment (LCA) which aims to identify, evaluate and conclude the environmental impact analysis of all stages of the waste transportation process in Panakkukang District, Makassar City. At this stage, the impact contribution at each stage of the process is analyzed to find out what emissions contribute to the environmental impact of all stages of the scenario and then compared with the scenario stage to obtain alternative recommendations that have the least environmental impact.

From the calculation results table above, it can be seen that for the armroll truck type of vehicle, the highest global warming potential (GWP) value is 28.5 kg CO2eq, namely on the Jl.Bahagia-TPA Tamangapa route with a distance of 12 km, a waste load of 4,962 tons, while the lowest global warming potential (GWP) value is on the Jl.middle ring road - TPA Tamangapa route of 11.9 kg CO2 eq with a distance of 5.5 km, a waste load of 3,754 tons.

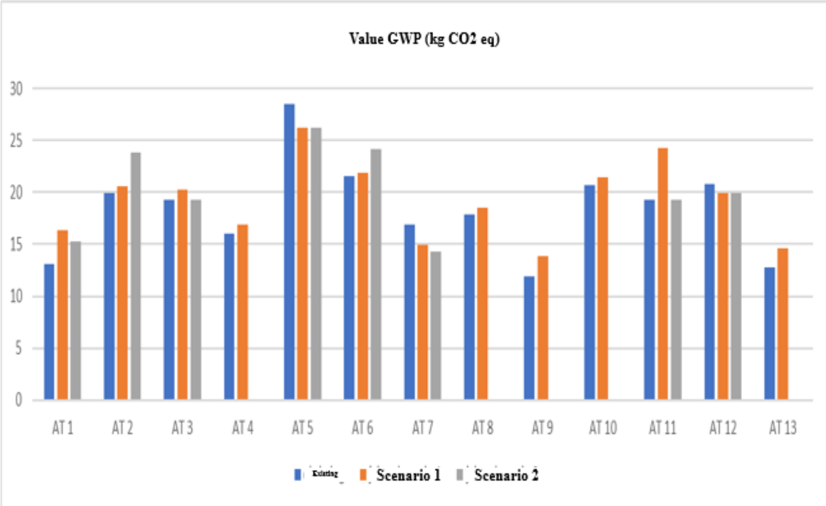

Figure 7. Comparison graph of GWP values between existing routes and scenario routes on armroll trucks

For the type of Dump truck vehicle (open back), the highest global warming potential (GWP) value is 59.4 Kg CO2 eq, namely on the route of Bosowa University - High Prosecutor's Office - Sucofindo - Amaris Hotel - H. Kalla Workshop - Telkom Pettarani Standby - Jl. Plantation - Tamangapa Landfill with a distance of 30 km and a load of 3 tons, while the lowest global warming potential (GWP) value is 19 Kg CO2 eq, namely on the route along the Tamamaung River - Standby - Jl.Sukaria Raya - Tamangapa Landfill, with a distance of 9.3 km and a load of 3.35 tons.

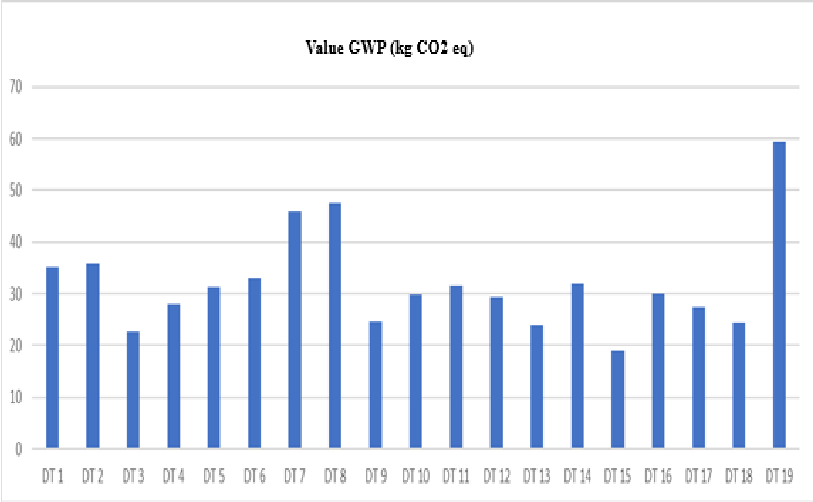

Figure 8. Comparison graph of GWP values between Dump truck routes

For the Tangkasaki type of vehicle (closed body), the highest global warming potential (GWP) value is 54.2 Kg CO2 eq, namely on the route jl. h. kalla - residence complex - jl. Cambajawayya - jl. Angkasa Raya 4 - Tello Baru dormitory - Barawaja complex and jln sadar - TPA Tamangapa with a distance of 23 km and a load of 5.135 tons, while the lowest global warming potential (GWP) value is 16.8 Kg CO2 eq, namely on the route jl. Janggo (standby) - TPA Tamangapa, with a distance of 7.05 km and a load of 5.229 tons of waste.

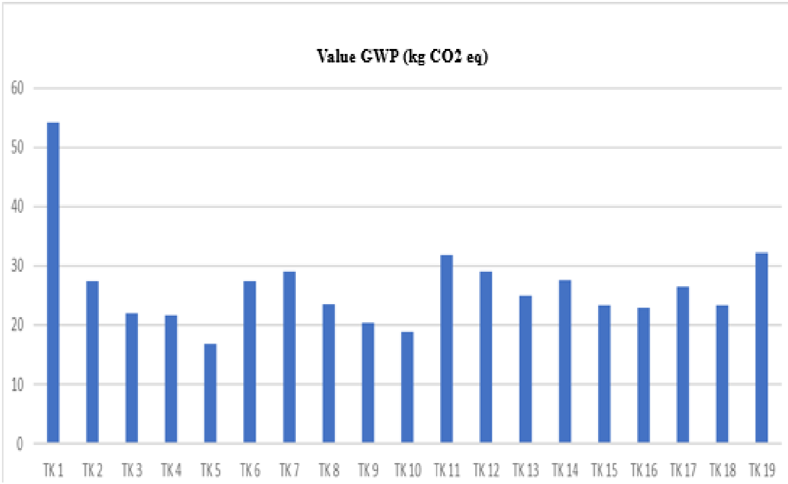

Figure 9. Comparison graph of GWP values between Tangkasaki routes

From the total waste transportation routes in Panakkukang sub-district (armroll truck, dump truck and Tangkasaki), the total global warming potential (GWP) value for the transportation routes that have been implemented so far is 1,352.64 kg CO2 eq. The comparison for all transportation routes can be seen in Figure 10 below.

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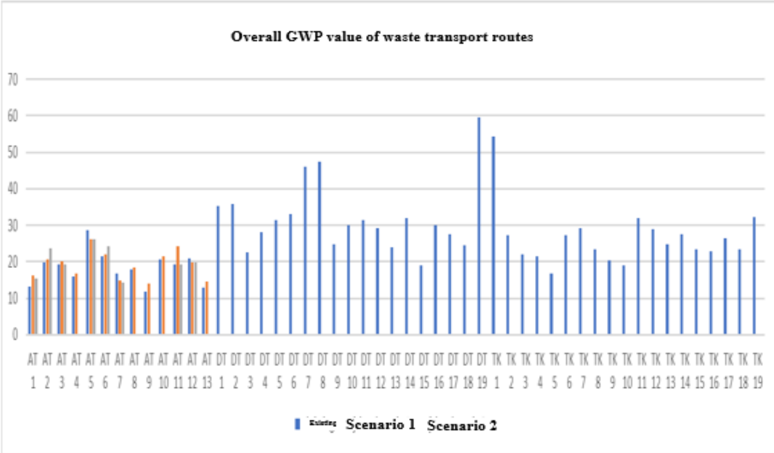

Figure 10. Comparison graph of GWP values between all routes in Panakkukang sub-district

CONCLUSION

Based on the results of the analysis that has been carried out, it can be concluded that the total GWP value of the armroll truck type garbage truck on the existing route is 236.6 kg CO2 eq, or an average of 18.35 kg CO2 eq per armroll unit. In contrast, for scenario route 1 the total GWP is 249.6 kg CO2 eq, or an average of 19.2 kg CO2 eq per unit and on scenario route 2 the total GWP value is 247.5 kg CO2 eq, or an average of 19.03 kg CO2 eq per armroll unit. Of the 13 existing routes on the armroll truck fleet, 10 routes are routes that have the lowest GWP values compared to the scenario routes, this is because these routes are the shortest routes. The total GWP value of the Dump Truck type waste transport vehicle is 611.1 kg CO2 eq, or an average of 32.163 kg CO2 eq per Dump Truck unit, while the total GWP value of the Tangkasaki type waste transport vehicle is 502.94 kg CO2 eq, or an average of 26.47 kg CO2 eq per Tangkasaki unit. In the dump truck and Tangkasaki units, the fleet that has a longer route with a larger load weight has a higher GWP value, so it can be concluded that to reduce the GWP value, it is necessary to pay attention to the transportation distance for each vehicle.

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