



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

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ABSTRACT

Global warming, induced by the effects of Greenhouse Gases (GHGs), is a major concern in the context of the global ecosystem. The Intergovernmental Panel on Climate Change (IPCC) has issued a serious warning that without serious handling of GHG emissions, the earth's temperature has the potential to increase drastically by up to 6.4°C. In facing this challenge, Life Cycle Assessment (LCA), as an analytical method, becomes an important instrument for evaluating the impact of a product or process throughout its life cycle. This research has a special focus on evaluating strategies for transporting waste from the Panakkukang sub-district to the Tamangapa final disposal site (TPA) in Makassar city. By comparing existing waste transportation routes and alternative scenarios, this research aims to identify transportation routes that have the smallest contribution to the Global Warming Potential (GWP). It is hoped that the results of this research can provide valuable guidance for the development of a sustainable waste transportation system in the city. Thus, this research not only has the potential to increase awareness of environmental impacts but can also make a significant contribution to efforts to create a friendly and sustainable environment in an increasingly urgent era of global warming.

Keywords: Global Warming Potential, Life Cycle Assessment, Transportation System

INTRODUCTION

Global warming, as a result of increasing atmospheric temperatures caused by the effects of greenhouse gases (GHG), is a serious issue in the ecosystem. The Intergovernmental Panel on Climate Change (IPCC) warns that without handling GHG emissions, the earth's temperature could increase drastically by up to 6.4°C (Ennemiri et al., 2024; Kristanto & Koven, 2019). Indonesia is committed to contributing to mitigating global warming by ratifying the

Kyoto Protocol in 2004 and the Paris Agreement in 2016, with a target of keeping global temperature rise below 2 degrees(Nascimento et al., 2022).

According to the Paris Agreement, the temperature rise threshold is set at 1.5°C. In an effort to achieve this target, Indonesia detailed its Nationally Determined Contribution (NDC) to reduce GHG emissions by 29% and 41% in 2030 (Ministry of Environment and Forestry, 2021);(Abi Suroso et al., 2022; Cahyono et al., 2022; Handayani et al., 2022; Kautzar et al., 2015; Tacconi & Muttaqin, 2019). Data from the Environment and Forestry Service of South Sulawesi Province records that in 2021, the province's greenhouse gas emissions will reach 40,370.42 Gg CO₂ Eq, with a contribution from the vehicle emissions sector going 20,602.51 Gg CO₂ Eq (Qodriyatun, 2021). The vehicle sector is the largest contributor to greenhouse gas emissions in the province, surpassing the IPPU, agriculture, forestry and waste sectors (Ulpiani et al., 2023).

Waste management is an important factor in the potential for global warming. Waste produces emissions that contribute to global warming through the transportation process, material processing, energy needs, and the entire process. Waste management based on Law Number 18 of 2008 is divided into three main categories: household waste, household-like waste, and specific waste (INDONESIA, 2008; Lathifah, 2022). Waste has a positive impact if managed well; it can be converted into energy or valuable products. However, inappropriate management can result in negative impacts on health, the ozone layer and environmental life. Makassar City, as the center of government, education, and trade in South Sulawesi, is experiencing an increase in population, which has an impact on waste production. In 2020, the city produced 997 tons of waste per day, with a controlled landfill system as the main management method. The increasing volume of waste and limitations of the Tamangapa Final Disposal Site (TPA) create challenges in waste management in Makassar City.

In the context of waste management, waste transportation is a sub-system that requires special attention. Optimizing waste transportation can increase operational efficiency and reduce environmental impacts. Life Cycle Assessment (LCA) is used to analyze the ecological burden of the waste life cycle, involving resource extraction, material production, use, and disposal (Farjana et al., 2019; Grzesik & Guca, 2011; Mah et al., 2018; Prasad et al., 2020; Turner et al., 2016). With this method, optimal waste transportation routes can be found to achieve operational efficiency and minimal environmental impact. This research aims to analyze the level of global warming potential (GWP) in the waste transportation system that has been implemented in the city of Makassar (Aditama, 2023).

Apart from that, this research also aims to evaluate strategies or scenarios that can be used as alternative routes for transporting waste from the Panakkukang sub-district to the Tamangapa final disposal site (TPA). By comparing the results between existing routes and scenario routes, this research aims to identify waste transport transportation routes that can make the smallest contribution to the Global Warming Potential (GWP). Thus, this research can

provide valuable information for the development of a more sustainable and environmentally friendly waste transportation system in the city of Makassar.

RESEARCH METHODS

Life Cycle Assessment (LCA) is generally used as a procedure or analytical method that includes aspects of compiling and evaluating inputs and outputs as well as the potential impact of a product or process throughout its life cycle. LCA consists of four components, namely: Goal and Scope Definition, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), Interpretation

The relationship between the four components above can be seen in the following diagram:

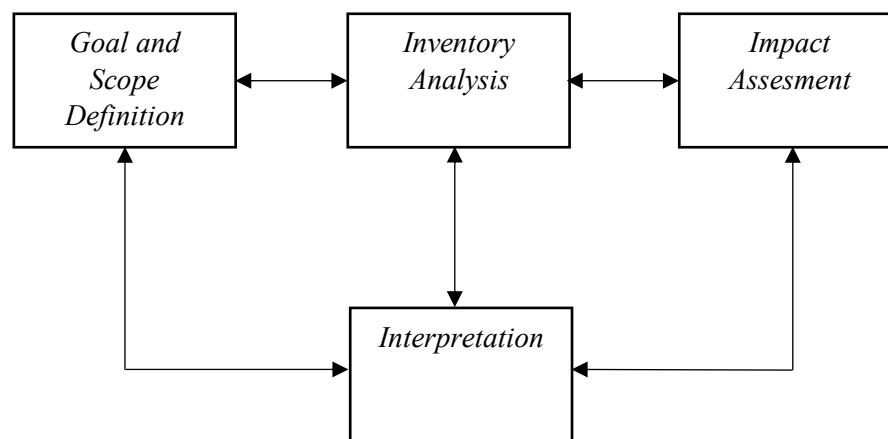


Figure 1 Relationship between Life Cycle Assessment (LCA) components

Source: Horne et al., 2009

RESULTS AND DISCUSSION

The waste transportation management system in the city of Makassar is handled individually in each sub-district, where each sub-district divides into two types of transportation systems, namely the fixed container system and the transport container system. In the fixed container system, dump truck (open bed) and Tangkasaki (closed bed) vehicles are used which use door to door and communal methods. Meanwhile, in the transport container system, waste is collected from containers placed in temporary disposal sites (TPS) spread across the Panakkukang sub-district. Panakkukang District has a fleet of 51 waste trucks, consisting of 13 armroll trucks, 19 dump trucks (open bed) and 19 Tangkasaki trucks (closed bed).

The waste transportation pattern in Panakkukang 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 vehicles.

There are 3 types of waste transportation facilities for waste trucks in Panakkukang sub-district, Makassar city, namely:

Dump Truck (open bed): in this type of dump truck vehicle, waste is transported from waste dumps located along the road/transportation route that has been determined for each

car to the Tamangapa TPA. The dump truck route is a walking route. The number of Dump truck-type vehicles operating in the Panakkukang sub-district is 19 units. Armroll Truck: This type of armroll vehicle transports waste containers, which are communal waste collection points. This truck carries waste from the container point and then takes it to Tamangapa TPA. The number of types of armroll trucks operating in the Panakkukang sub-district is 13 units. Tangkasaki (closed bed): The tangkasaki-type vehicle is a modification of the fast bed truck. This truck is divided into two systems, namely a transportation system that picks up waste along the walking route and a standby system that receives and carries waste that is transported by a 3-wheeled vehicle used by the Panakkukang sub-district to reach waste generation in residential areas that cannot be reached by this type of waste truck. dump trucks and no containers available as communal waste disposal containers. The number of Tangkasaki-type vehicles in the Panakkukang sub-district is 19 units.

Life cycle assessment analysis of the waste transportation system in this research uses Simapro v.9.5 software. The method used to estimate the magnitude of the environmental impact that occurs is the 2000 CML 2 baseline method. The 2000 CML 2 baseline method was chosen for this research because it is based on the type of waste produced from the waste transportation process to the landfill, namely CO and CO₂ gas. Burning fuel in garbage truck transportation will produce gases that are released into the environment, namely CO and CO₂, the impact of which can trigger the Global Warming Potential (GWP).

In this research, scenario comparisons were carried out on armroll truck vehicle types to compare the environmental impact produced on the existing route with the scenario route so that from the route comparison it can be seen which route has the smallest environmental impact, especially Global Warming Potential. Meanwhile, the dump truck and tangkasaki type vehicles were only analyzed without comparing with the scenario because the dump truck and tangkasaki transportation system is a walking route transportation method. The results of data processing in LCI are entered into Simparo in the process section by inputting the type of vehicle entered into the Simapro data base.

Life Cycle Impact Assessment is a stage that aims to group and assess the magnitude of the impact on the environment in each process of each route, both existing routes and scenario routes on the environment based on input data at the inventory stage.

Global Warming Potential (GWP) states the potential for global warming caused by greenhouse gas emissions over 100 years. GWP is expressed in kg CO₂ eq. Equivalence values are issued periodically by the International Panel on Climate Change (IPCC). The compounds that contribute most to global warming potential are CO₂ and CH₄. This impact is expressed in weight units of kg CO₂ so that other compounds that are not CO₂ but contribute to global warming are equivalent to the weight of CO₂.

Impact characterization will determine the magnitude of the impact that has been classified for the GWP category. The TKM results for each vehicle, it is then input so that the resulting Global warming Potential value for each car is as follows:

GWP (Global Warming Potential) analysis for Armroll Truck and Dump Truck type waste transport trucks in the Panakkukang sub-district shows quite varied results. The following is a summary of the analysis results for each lane and vehicle:

Arm roll Truck

Line 1 (DD 9055 AB)

Existing: GWP = 13.1 kg CO₂ eq

Scenario 1: GWP = 16.3 kg CO₂ eq

Scenario 2: GWP = 15.3 kg CO₂ eq

Conclusion Line 1: The existing line has the lowest GWP (13.1 kg CO₂ eq).

Line 2 (DD 9213 A)

Existing: GWP = 19.9 kg CO₂ eq

Scenario 1: GWP = 20.6 kg CO₂ eq

Scenario 2: GWP = 20.6 kg CO₂ eq

Conclusion Line 2: The existing line has the lowest GWP (19.9 kg CO₂ eq).

Line 3 (DD 8391 AP)

Existing: GWP = 19.3 kg CO₂ eq

Scenario 1: GWP = 20.2 kg CO₂ eq

Scenario 2: GWP = 19.3 kg CO₂ eq

Conclusion Line 3: The existing line has the lowest GWP (19.3 kg CO₂ eq).

(The above process is repeated for Line 4 to Line 13)

Dump Trucks

Waste Transport Routes for Dump Truck Vehicle Types

Jl. Pengayoman – TPA Tamangapa: GWP = 35.3 kg CO₂ eq

Jl. Racing Center – TPA Tamangapa: GWP = 35.8 kg CO₂ eq

Jl. Batua – TPA Tamangapa: GWP = 22.6 kg CO₂ eq

Jl. Abd. Dg. Sirua – Tamangapa TPA: GWP = 28.1 kg CO₂ eq

Jl. Financial Complex – Tamangapa TPA: GWP = 31.3 kg CO₂ eq

Jl. Topaz Raya – TPA Tamangapa: GWP = 33 kg CO₂ eq

Jl. Abu Bakar Lambogo – TPA Tamangapa: GWP = 45.9 kg CO₂ eq

Jl. Maccini Raya – TPA Tamangapa: GWP = 47.5 kg CO₂ eq

Jl. Toddopuli Raya – TPA Tamangapa: GWP = 24.7 kg CO₂ eq

Jl. A.P. Pettarani Kiri – Tamangapa Landfill: GWP = 29.9 kg CO₂ eq

Jl. A.P. Pettarani Kanan – Tamangapa Landfill: GWP = 31.5 kg CO₂ eq

Jl. Saripa Raya (standby) – TPA Tamangapa: GWP = 29.3 kg CO₂ eq

Jl. Babussalam (standby) – TPA Tamangapa: GWP = 24 kg CO₂ eq

Jl. Inspeksi Kanal (standby) – TPA Tamangapa: GWP = 32 kg CO₂ eq

Jl. Tamamaung (standby) – Jl. Sukaria Raya – TPA Tamangapa: GWP = 19 kg CO₂ eq

Jl. Urip Sumiharjo – Tello Baru Village Head Office _ Amkop (standby) – Jl. Janggo Paropo – TPA Tamangapa: GWP = 30 kg CO₂ eq

Jl. Urip Sumoharjo – Lorong Tamajene – Kodam Hasanuddin – Aspol Panaikang – TPA Tamangapa: GWP = 27.4 kg CO₂ eq

Carrefour – Komp. Lili – Bougenville I and II – North Hertasing – TPA Tamangapa: GWP = 24.4 kg CO₂ eq

Bosowa University – High Court – Sucofindo – Hotel Amaris – Bengkel H. Kalla – Telkom Pettarani standby – Jl. Perkebunan – TPA Tamangapa: GWP = 59.4 kg CO₂ eq

Dump Truck Conclusion: The route with the lowest GWP is Jl. Batua – TPA Tamang
Here are the GWP values for each line:

Pampang I – Pampang II – Pampang Raya – Graha Pampang – TPA Tamangapa route (10 km, weight 14.57 tons):

GWP: 24.9 kg CO₂ eq

Normalized: 9.87×10^{-11}

Route jl. Urip Sumoharjo Ir II – jl. Adipura – Jl. Urip Sumoharjo Ir. 4 – R.S. Primaya – Tamangapa TPA (12 km, weight 13.43 tonnes):

GWP: 27.6 kg CO₂ eq

Normalization: 1.09×10^{-10}

Route jl. Gotong Royong – jl. Bakti – jl. A.P Pettarani III – jl. Abdullah Daeng Sirua III – Tamangapa TPA (9.8 km, weight 13.95 tonnes):

GWP: 23.4 kg CO₂ eq

Normalization: 9.27×10^{-11}

Route jl. Penjernihan – jl. Baitul Rahman – Gardenia Housing – Graha Track – Mustika Mulia Housing – Tamangapa TPA (10 km, weight 13.40 tons):

GWP: 22.9 kg CO₂ eq

Normalization: 9.08×10^{-11}

Route jl. A.P. Pettarani II – jl. Sukaria morning market – jl. Muhammad Saleh – jl. Sukamaju – jl. Sukamulya – jl. A.P. Pettarani VII and VIII – TPA Tamangapa (12 km, weighing 15 tonnes):

GWP: 26.4 kg CO₂ eq

Normalization: 1.22×10^{-10}

Jl. Janggo route (standby) – Tamangapa TPA (9.4 km, weight 14.55 tonnes):

GWP: 23.4 kg CO₂ eq

Normalization: 9.27×10^{-11}

BTN Citra Tello – TPA Tamangapa route (13 km, weight 14.45 tonnes):

GWP: 32.2 kg CO₂ eq

Normalization: 1.27×10^{-10}

Each GWP value reflects the greenhouse gas impact produced by a particular waste transportation route. Normalization provides an understanding of how big the effect is compared to a certain value. The lower the normalized value, the lower the relative impact.

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 sub-district, Makassar city. At this stage, the impact

contribution at each process stage is analyzed to find out what emissions contribute to the environmental impact of all scenario stages and then compared with the scenario stages to obtain alternative recommendations that have the least environmental impact.

From the table of calculation results above, it can be seen that for the arms roll 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 and a waste load of 4,962 tons. , while the lowest global warming potential (GWP) value was on the Jl. Middle Ring Road – TPA Tamangapa route of 11.9 kg CO₂ eq with a distance of 5.5 km, with a waste load of 3,754 tons.

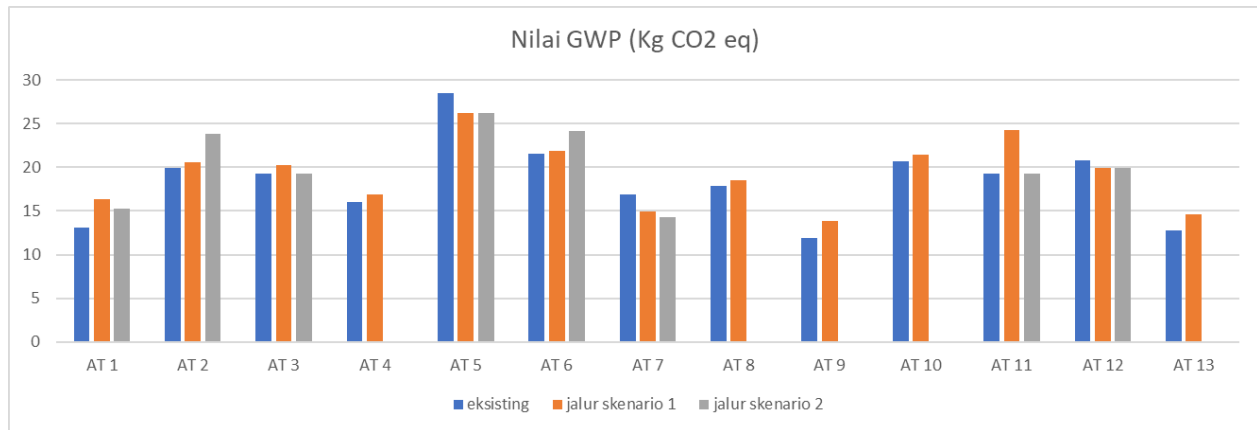


Figure 2 Comparison graph of GWP values between existing routes and scenario routes on arm roll trucks

For the Dump truck type of vehicle (open bed), the highest global warming potential (GWP) value is 59.4 Kg CO₂ eq, namely on the route from Bosowa University - High Prosecutor's Office - Sucofindo - Amaris Hotel - Workshop H. Kalla - telkom pettarani stand by - jl. Plantations – TPA Tamangapa with a distance of 30 km and a load weighing 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 – TPA Tamangapa, with a distance of 9.3 km and a payload weighing 3.35 tons

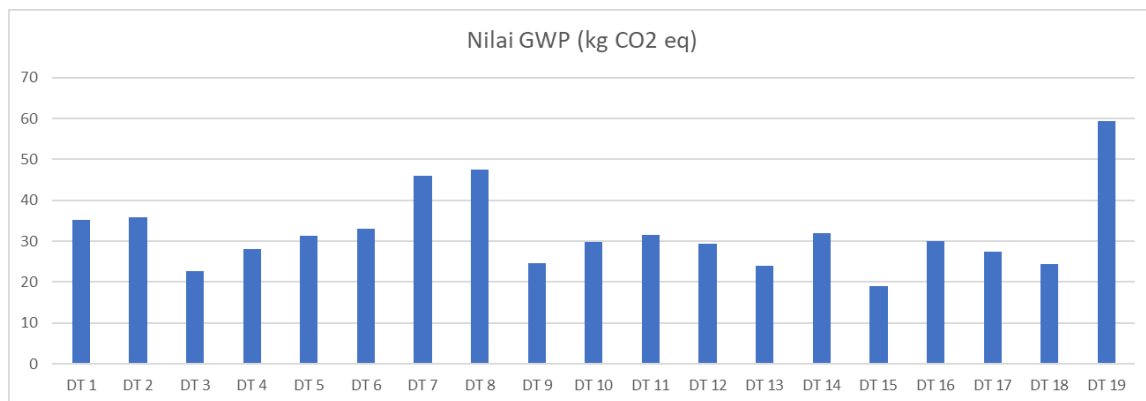


Figure 3 Comparison graph of GWP values between Dump truck routes

For the Tangkasaki vehicle type (closed bed), the highest global warming potential (GWP) value is 54.2 Kg CO2 eq, namely on the Jl. h. Kalla - Komp Residence - Jl. Cambajawayya - jl. Angkasa Raya 4 - Tello Baru Dormitory - Komp Barawaja and Jalan Awareness - TPA Tamangapa with a distance of 23 km and a load weighing 5,135 tons, while the lowest global warming potential (GWP) value is 16.8 Kg CO2 eq, namely on the Jl route.Janggo (standby) – Tamangapa landfill, with a distance of 7.05 km and a load weighing 5,229 tons of waste.

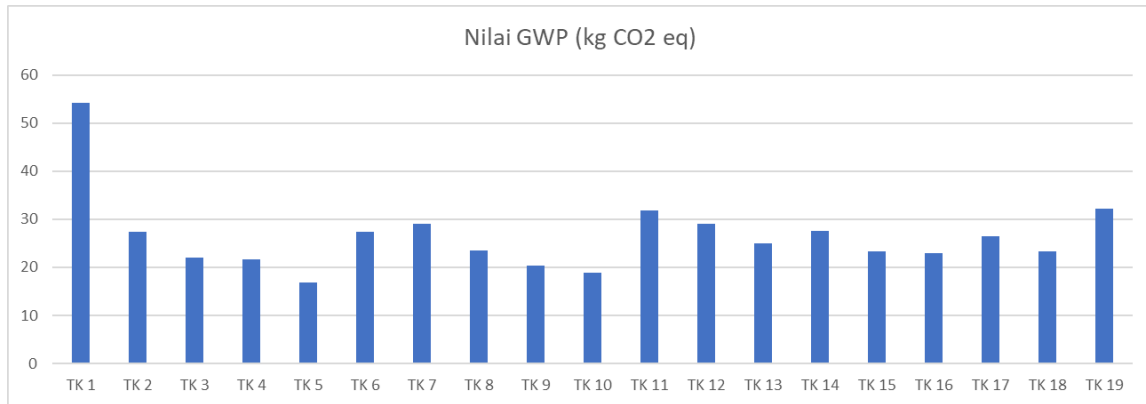


Figure 4. Comparison graph of GWP values between Tangkasaki routes

From the total waste transportation routes in Panakkukang sub-district (armroll trucks, dump trucks and Tangkasaki), the total global warming potential (GWP) value is 1,352.64 kg CO2 eq.

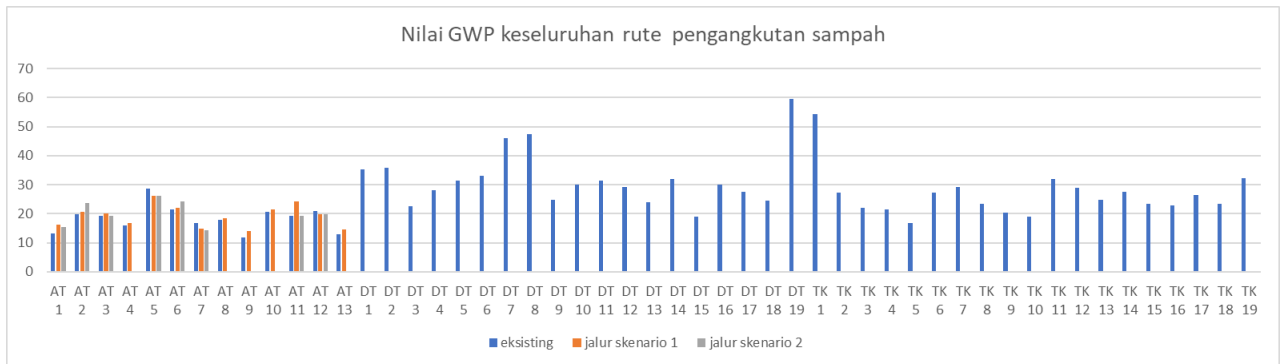


Figure 5. Comparison graph of GWP values between overall routes in Panakkukang sub-district

CONCLUSION

In this research, several conclusions can be drawn. First, the total Global Warming Potential (GWP) value for arm roll trucks on existing routes is 236.6 kg CO2 eq, with an average of 18.35 kg CO2 eq per arm roll unit. Meanwhile, for the scenario, one route, the total GWP is 249.6 kg CO2 eq or an average of 19.2 kg CO2 eq per unit, and in scenario two routes, the total GWP value is 247.5 kg CO2 eq or an average of 19.03 kg CO2 eq per arm roll unit. Second, of the 13 existing routes in the arms roll truck fleet, ten routes have the lowest GWP values compared

to the scenario route because they are the shortest routes. Third, the total GWP value for Dump Truck type waste transport vehicles is 611.1 kg CO₂ eq or an average of 32.163 kg CO₂ eq per Dump Truck unit. Fourth, the total GWP value for Tangkasaki-type waste transport vehicles is 502.94 kg CO₂ eq, with an average of 26.47 kg CO₂ eq per Tangkasaki unit. Finally, for dump trucks and Tangkasaki units, fleets with longer tracks and larger load weights have higher GWP values, indicating the need to pay attention to transportation distances to reduce GWP values.

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