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OPTIMIZATION OF WASTE MANAGEMENT THROUGH TRANSPORT EFFICIENCY AND CARBON DIOXIDE (CO2) EMISSION CONTROL IN PANGKAJENE DAN KEPULAUAN REGENCY

Erika Asriyanti [1]*, Mursyid [2] and Andi Santi [3]

[1,2] Pengelolaan Lingkungan Hidup, Sekolah Pascasarjana, Universitas Hasanuddin, Makassar.
[3] Teknologi Pertanian, Pengolahan dan Penyimpanan Hasil Perikanan,
Politeknik Pertanian Negeri Kepulauan
*Corresponding Author Email: erikaasriyanti1712@gmail.com

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Abstract

This research aims to (1) examine the optimization of waste transportation routes based on distance traveled, route, and fuel consumption in the Pangkep Regency area, (2) examine waste transportation services based on population and the generation of transported waste, (3) calculate CO_2 (Carbon Dioxide) emissions produced from waste transportation. This research took 4 densely populated sub-districts, namely Pangkajene, Minasate'ne, Bungoro, and Labakkang. This research uses Network Analysis to analyze existing routes for transporting waste, then create alternative routes starting from vehicle travel time, volume of waste transported, number of transportation cycles, vehicle speed, and distance traveled from TPS (Temporary Disposal Place) to TPA (Final Disposal Site). Meanwhile, the amount of CO_2 (Carbon Dioxide) emissions produced by waste vehicles was analyzed using the IPCC (Intergovernmental Panel on Climate Change) Tier-1 method. The research results show that (1) the total distance traveled on the existing route by waste vehicles is 361.77 km with 2 trips per day, and the total fuel consumption is 48,480 liters/year. Meanwhile, the total distance traveled for the optimization route is 443.34 km with 2 cycles per day and total fuel consumption is 191,436 liters/year. (2) The level of waste transportation service in existing conditions is 17,57% with the amount of waste transported to the Taraweang landfill at 21,09 Tons. Meanwhile, under optimization conditions, the service percentage increased by 186,45% and the amount of waste transported to the Taraweang landfill was 201,29 Tons. (3) CO_2 emissions resulting from waste transportation in existing conditions are 12.94 tons/year. Meanwhile, CO_2 emissions produced under optimization conditions are 51.07 tons/year.

Keywords: Waste Transport Routes, CO_2 Emissions.

INTRODUCTION

Waste can be defined as something that is unused, unused which comes from human activities. Because waste has the characteristic of being unused, it will tend to accumulate. Environmental conditions that are dirty, damp, and unmanaged can cause environmental and aesthetic problems, block waterways, and have an impact on health transmitted by disease vectors.

Indonesia produced 67.8 million tonnes of waste in 2020. Based on data from the Ministry of Environment and Forestry (KLHK), waste in Indonesia is in first place at 37.3% coming from household activities. This will continue to increase as the population increases. Pangkajene Islands Regency (Pangkep) is a district that has many islands and a population of 345,775 people in 2020.

Problems arise because waste management is influenced by environmental conditions, population growth, population mobility, community behavior and community consumption patterns (Purwoko et al., 2019).

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Various studies using scientific methods and approaches have been carried out by many researchers. One of them is a waste management approach that utilizes geospatial information (Purwoko et al., 2019). Geospatial information can be interpreted as modeling that can display earth surface objects such as buildings, rivers, roads, and others in a *layer* data. Applications that help with geospatial information are Geographic Information Systems (GIS). Some of the benefits that can be obtained from using a Geographic Information System (GIS) include the ease of interpreting the data presented considering that Geographic Information Systems (GIS) provide more of a visual character in the form of maps. Maps themselves are divided into several types, for example earth maps, thematic maps, image maps and others which can present location information, explanations and associations about the location.

The use of Geographic Information Systems (GIS) can improve waste management by mapping routes and precise locations in determining the location of Temporary Storage Places (TPS) to Final Disposal Places (TPA). Remember that the location of the Final Disposal Site (TPA) or Temporary Storage Site (TPS) greatly influences the distribution pattern of environmental problems that originate from the accumulation of waste. Utilization of Geographic Information Systems (GIS) in terms of waste management can be done by selecting waste transport routes, location points for final disposal sites (TPA), waste volume predictions and so on (Ulil Absor, 2024).

The Geographic Information System (GIS) was used by one of the researchers, Apriyanti et al., (2018), in terms of waste management by analyzing waste transportation routes from Temporary Storage Places (TPS) to Final Disposal Places (TPA) using the method *Network Analysis* and *Graph*. Then the results of the shortest route data that have been obtained are calculated using fuel consumption to complete the waste transportation service data which is presented in the form of a 1:25,000 scale map. Of course, transporting waste requires transportation facilities to transport the waste from the Temporary Storage Site (TPS) to the Final Disposal Site (TPA). Transportation is also the third largest contributor to Green House Gas (GHG) emissions, one of which is Carbon Dioxide (CO_2). According to the International Energy Agency (IEA), in 2020 total carbon dioxide (CO_2) amounted to 7.2 Gt (Gigatons) of total Carbon Dioxide (CO_2) namely 33.9 Gt (Gigaton).

Waste transportation is a consideration because emissions from waste transportation are influenced by the waste vehicle, such as the type of vehicle, the fuel used and the distance the waste is transported (Kartika Hariyanto, Kurniati, & Helmi, 2024). Greenhouse Gas (GHG) emissions are expected to increase with the increase in the amount of waste produced if it is not managed properly.

According to Pristanto, (2021), transporting waste is a consideration because greenhouse gas emissions will arise from transporting waste, emissions from transporting waste are influenced by waste transport vehicles such as the type of vehicle, fuel used, vehicle carrying capacity and driver behavior when driving. So it is necessary to calculate emissions using the IPCC (*Intergovernmental Panel On Climate Change*) Tier 1 method for calculating greenhouse gas emissions such as CO_2 (Carbon Dioxide) while measuring the distance traveled by transporting waste using *Google Maps, Network Analysis,* and *Google Earth*.

Various studies have been carried out regarding waste transportation in various cities in Indonesia. From the results of the research that has been carried out, several interesting findings emerged. Diniyah F.W. Kresnawati K.D. & Apriyanti D. (2018) revealed the results of an analysis of the shortest route and fuel consumption in Bogor City, while Himawan Roy (2017) found that waste transportation in South Surabaya uses arm rolls and compactor trucks. Indriani Sarah (2020) examined greenhouse gas emissions from transporting waste in the city of Yogyakarta with low population density, while Mahyudin R.P, Chairul A. & Ridha R.M. (2016) and Pristanto Ridho Ramandika (2021) also investigated greenhouse gas emissions from waste transportation in other cities. Apart from that, Rais Renas Wira Fact (2021) evaluated the waste transportation system in Ponorogo and suggested increasing vehicle traffic at several service locations.

Based on this problem, this research aims to analyze waste management using waste transportation routes in Pangkep Regency and calculate CO emissions2 (Carbon Dioxide) produced from waste transportation using the Tier 1 method based on the IPCC (*Intergovernmental Panel On Climate Change*) 2006 and Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number 6 of 2022 concerning the Tier-1 National Waste Management Information System. The benefits of this research include providing references for learning and information about waste transportation systems and greenhouse gas emissions, providing insights and contributions for policymakers regarding greenhouse gas emissions issues, providing input for policymakers about waste transportation routes, and providing information and references for the community and other researchers about waste management in Pangkep Regency and related topics for future research.

METHOD

This research uses quantitative methods using GIS (Geographic Information System) software to determine the shortest and alternative routes for transporting waste. The steps taken include determining travel time, waste volume, distance from TPS to TPA, number of trips and vehicle speed. Analysis was also carried out on the amount of CO2 emissions produced by waste transportation vehicles based on the IPCC Tier-1 method. This methodology is supported by hardware and software which includes an Asus laptop, 4 GB RAM, Core i5 processor, as well as Google Maps, Google Earth, and ArcGIS 10.1 software for data processing and route map creation.

Data collection was carried out through direct observation in the field (primary data) and using secondary data sources such as regional maps, waste transportation routes and population. Data analysis includes evaluation of the existing condition of the waste transportation system, optimization of the transportation system, volume of waste generation, and calculation of CO2 emissions. Analysis steps include data verification, measuring distance and travel time, as well as calculating the percentage of waste transportation services and CO2 emissions based on IPCC Tier-1.

DATA ANALYSIS AND FINDINGS

Analysis of Optimizing the Waste Transport System in Pangkep Regency

Alternative route optimization results come from previous existing routes. Alternative routes are obtained via *network analysis* in the GIS (Geographic Information System) application with a rotation of 2 cycles/day. Alternative routes include most routes that existing routes have not traversed. Alternative routes can be seen in table 10. Below. Meanwhile, pictures of alternative routes can be seen in attachment 1.

Table 1: Alternative Routes for Waste Transport Vehicles

No	Number of vehicles	Transportation type	Vehicle Capacity (m^3)	Alternative route
1	DD 8081 E	Dump Truck	6	Sultan Hasanuddin Axis Road, Palopo Axis Road, Kabba Road, Tonasa 1 Axis Road, Wajjennang Road, Education Road, North Bontoa Road, Minasatene Road, Scout Road, Jendral Sukowati Road, Arung Kajuara Road, Tonasa 2 Axis Road, Tabo Tabo Axis Road
2	DD 8085 E	Arm Roll	6	Sultan Hasanuddin axis road Jalan H. Unda Gasing, Jalan Jeruk, Jalan Taladilau, Jalan Balai Desa, Jalan Biringkassi Jalan Poros Palopo, Jalan Handi Muhali, Jalan Poros Palopo, Jalan Sampakang
3	DD 8107 E	Dump Truck	6	Rose Street, Sun Street Jalan Cendana, POLRI Dormitory, Pangkep Square, Jalan Poros Palopo-Makassar
4	DD 8108 E	Dump Truck	6	Jalan Poros Palopo-Makassar, Jalan Poros Maros-Pangkep, Jalan Poros Tonasa 1, Jalan Nangka, Jalan Jeruk, Jalan Raja Siang Biringkassi Street, Taladilau Street, Tabo-tabo Street
5	DD 8109 E	Dump Truck	6	Jalan Matahari, Jalan Bontoa Utara, Jalan Minasatene, Jalan Pramuka, Jalan Arung Kajuara Jalan Poros Bontoa Siloro, Jalan Poros Tonasa 2, Jalan Poros Tabo Tabo
6	DD 8117 E	Dump Truck	6	Jalan Matahari, Jalan Cendana, Jalan Jend. Sukowati, Jalan Sultan Hasanuddin, Jalan Andi Maruddani, Jalan Taladilau, Jalan Poros Tonasa 2, Jalan Axis Tabo Tabo
7	DD 8122 E	Arm roll	6	Jalan Matahari, Jalan Cendana, Jalna Jend. Sukowati, Jalan Jeruk, Jalan Poros Barru-Makassar, Jalan Andi Maruddani, Jalan Bontowa Raya, Jalan Poros Maros-Pangkep, Jalan Poros Pangkajene-Barru, Jalan Poros Batiling, Jalan Poros Tabo-tabo
8	DD 8124 E	Arm Roll	6	Jalan Matahari, Jalan Bontoa Utara, Jalan Minasatene, Jalan Cendana Timur, Jalan Jend. Sukowati, Jalan Sultan Hasanuddin, Jalan Nangka Jalan Jeruk, Central Market Jalan Raja Siang, Jalan Poros Maros-Pangkep, Jalan Biringkassi, Jalan Poros Tabo-tabo
9	DD 8183 E	Dump Truck	6	Jalan Matahari, Jalan Cendana, Jalan Jend. Sukowati, Jalan Sultan Hasanuddin, Jalan Mappasaile, Jalan Raja Siang Jalan Taladilau, Jalan Biringkassi, Jalan Poros Pangkajene-Barru, Jalan Sampakang, Jalan Poros Padanglampe
10	DD 8827 E	Arm Roll	6	Jalan Sultan Hasanuddin, Jalan K.H. Ahmad Dahlan, Jalan Pelelangan, Jalan H. Unda Gasing, Jalan Merdeka Jalan Mappasaile, Jalan Jend. Sukowati, Jalan Arung Kajuara, Jalan Poros Bontoa Siloro, Jalan Poros Tonasa 2 Jalan Poros Tabo-tabo
11	DD 9022 E	Arm Roll	6	Jalan Matahari, Jalan Cendana, Jalan Jend. Sukowati, Jalan Sultan Hasanuddin, Jalan Nangka Jalan Jeruk, Jalan Raja Siang, Jalan Biringkassi, Jalan Poros Maros-Pangkep, Jalan Poros Batiling, Jalan Poros Tabo-tabo
12	DD 9028 E	Dump Truck	6	Jalan Matahari, Jalan Bontoa Utara, Jalan Minasatene, Jalan Kelapa, Jalan Penas VII, Jalan Rumba, Jalan Wirakarya, Jalan Pramuka, Jalan Arung Kajuara, Jalan Poros Tonasa 2, Jalan Poros Tabo-tabo

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Optimizing Alternative Route Waste Transport Services

To get the percentage value of alternative waste transportation services, first collect village/sub-district data in Pangkajene and Islands Regency in 2021, then multiply it by an estimation factor of 0.4 kg/person/day.

After the results of the volume of waste that can be transported have been obtained. The total waste volume is obtained from figures from existing routes.

Then, to calculate the percentage, the value of the total volume of waste that can be transported is divided by the total volume of waste transported to the landfill multiplied by 100 percent. Can be shown in table 11.

Table 2: Percentage of Waste Transportation Services in Pangkep Regency

No	Number of vehicles	Total Volume of Waste Transported to Taraweang Landfill (kg)	Total Volume of Waste That Can Be Transported to Taraweang Landfill (kg)	Percentage of Waste Transportation Services (%)
1	DD 8081 E	8.374	16.933	202,22
2	DD 8085 E	21.434	22.065	102,94
3	DD 8107 E	3.964	3.964	100,00
4	DD 8108 E	15.385	16.164	105,06
5	DD 8109 E	10.264	11.088	108,03
6	DD 8117 E	9.088	13.557	149,18
7	DD 8122 E	12.199	13.512	110,77
8	DD 8124 E	13.769	19.588	142,26
9	DD 8183 E	5.863	16.882	287,94
10	DD 8827 E	9.684	24.924	257,36
11	DD 9022 E	4.908	25.398	517,49
12	DD 9028 E	11.174	17.220	154,11
	Total	**126.106**	**201.295**	**186,45**

Based on the table above, after optimizing the route, the overall volume of waste increased to 201.29 tons. Due to the increase in the number of routes traveled by each waste vehicle.

The average waste that can be transported is 186.45%. This shows that the waste generation on the existing route previously amounted to 126.10 tons, which was completely covered by the optimization of the waste transportation route.

Optimization of distance, time and speed of waste transportation

Mileage is obtained by using *network analysis* in GIS applications (*Geographic Information System*).

The routes that have been obtained previously come from the results of existing routes. Then the calculation of travel time is obtained using the formula speed equals distance divided by time. It can be seen in table 12 below.

Table 3: Optimization of Distance, Speed and Travel Time of Waste Transporting Vehicles

No	Number of vehicles	Number of Rites (Rit/day)	Mileage DA (km)	RE Mileage (km)	Traveling time RA (Minutes)	Traveling time RE (You went)	Speed Vehicle (km/h)
1	DD 8081 E	2	45,02	35,29	54,02	54,02	50
2	DD 8085 E	2	61,45	45,55	73,74	54,66	50
3	DD 8107 E	2	5,34	4,46	6,41	5,35	50
4	DD 8108 E	2	57,05	38,65	68,46	68,46	50
5	DD 8109 E	2	21,10	22,75	31,65	31,65	40
6	DD 8117 E	2	47,83	32,40	57,40	57,40	50
7	DD 8122 E	2	58,45	43,27	70,14	51,92	50
8	DD 8124 E	2	27,90	26,40	33,48	31,68	50
9	DD 8183 E	2	38,17	31,51	57,26	57,26	40
10	DD 8827 E	2	30,31	30,80	36,37	36,96	50
11	DD 9022 E	2	25,81	21,93	30,97	26,32	50
12	DD 9028 E	2	24,71	28,76	37,07	37,07	40
Rate-rate			**36,93**	**30,15**	**46,41**	**38,25**	**47,5**

The number of routes remains the same for different alternative routes. The average distance traveled was 36.93 km, while the distance traveled on the existing route was 30.15 km. This is due to the increase in the number of alternative routes.

Then the average travel time is 46.41 minutes, while the travel time in existing conditions is 38.25 minutes. The more waste that is transported, the longer the travel time from the waste source points to the TPA (Final Processing Place).

Recapitulation of Comparison of Existing Conditions and Optimization Conditions

A comparison of waste vehicles in existing and optimized conditions can be seen in the following table.

Table 4: Comparison of waste vehicles in existing and optimized conditions

Parameter	Existing	Optimization	Percentage (AND THE)
Amount of waste transported (tons)	21,09	201,29	10,48%
Percentage of Waste Transportation Services (%)	17,57	186,45	9,42 %
distance (km)	30,15	36,93	81,64 %
Speed (km/h)	47,5	47,5	47,5 %
Time (minutes/rit)	38,25	46,41	82,42 %

Based on the table above, a comparison between existing and optimized conditions gives us an idea that the amount of waste generated under existing conditions is 21.09 tonnes, whereas under optimal conditions it can transport 201.29 tonnes.

Thus, only 10.48% of waste is transported when compared to using the alternative route (optimal conditions). Waste transportation services in existing conditions can serve 17.57%, while in optimal conditions they can serve 17.57% **186,45**%.

The figure shows that only 9,42% of transportation services in existing conditions compared to alternative routes. This is because existing conditions do not yet cover most of the waste transportation services in optimal conditions.

The average distance in existing conditions is 30.15 km. Meanwhile, the average distance traveled under optimal conditions is 36.93 km. The distance in the optimization condition increases because there are more routes taken.

The speed of existing conditions and optimization has not changed. Travel time in existing conditions averages 38.25 minutes/rit, while in optimization conditions the average is 46.41 minutes/rit. This affects the distance and route traveled.

CO Emission Analysis$_2$ (Carbon Dioxide) from Waste Transport Activities

Waste transportation activities produce CO emissions$_2$ (Carbon Dioxide) due to CO emissions$_2$ (Carbon Dioxide) is the most dominant emission in land transportation. CO calculation$_2$ (Carbon Dioxide) is carried out in the existing conditions of the waste transportation system and optimization of waste transportation.

Fuel Consumption of Waste Transporting Vehicles Existing Conditions

It can be seen that the average rotation for each transport vehicle is 2 cycles per day. Due to irritation, the distance traveled for each vehicle is also different, which can affect fuel usage. Fuel consumption for waste transport vehicles is 202 liters/day, while annually it ranges from 48,480 liters/year. Can be seen in the table below.

Table 5: Fuel Consumption of Waste Transporting Vehicles in Existing Conditions

No	Number of vehicles	Number of Rites	Fuel Type	Fuel Consumption		
		(Rit/day)		Liters/day	Liters/month	Liters/year
1	DD 8081 E	2	Solar	14	280	3.360
2	DD 8085 E	2	Solar	19	380	4.560
3	DD 8107 E	2	Solar	17	340	4.080
4	DD 8108 E	2	Solar	15	300	3.600
5	DD 8109 E	2	Solar	17	340	4.080
6	DD 8117 E	2	Solar	15	300	3.600
7	DD 8122 E	2	Solar	19	380	4.560
8	DD 8124 E	2	Solar	18	360	4.320
9	DD 8183 E	2	Solar	17	340	4.080
10	DD 8827 E	2	Solar	17	340	4.080
11	DD 9022 E	2	Solar	17	340	4.080
12	DD 9028 E	2	Solar	17	340	4.080
Total				202	4.040	48.480

CO2 emissions resulting from existing waste transport vehicles

To calculate CO emission values$_2$ Existing carbon dioxide from waste transport vehicles using diesel fuel is calculated by multiplying the energy consumption (TJ) by the tier-1 emission factor from IPCC 2006.

The emission factor for vehicles using diesel fuel is 74,100 kg/TJ. To calculate energy consumption (TJ), namely fuel consumption multiplied by the heating value of diesel, namely $36x10^{-6}$ TJ/liter or 0.000036. So the results can be seen in table 15.

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Table 6: CO Emissions₂ resulting from Existing Condition Waste Transport Vehicles

No	Number of vehicles	Number of Rites	Fuel Type	Total Mileage	Fuel consumption	CO2 emissions	
		(Rit/day)		(km/day)	Liters/year	kg/year	Tons/year
1	DD 8081 E	2	Solar	35,29	3360	896,31	0,90
2	DD 8085 E	2	Solar	**45,55**	4560	1216,43	1,22
3	DD 8107 E	2	Solar	4,46	4080	1088,38	1,09
4	DD 8108 E	2	Solar	38,65	3600	960,34	0,96
5	DD 8109 E	2	Solar	22,75	4080	1088,38	1,09
6	DD 8117 E	2	Solar	32,40	3600	960,34	0,96
7	DD 8122 E	2	Solar	**43,27**	4560	1216,43	1,21
8	DD 8124 E	2	Solar	26,40	4320	1152,40	1,15
9	DD 8183 E	2	Solar	31,51	4080	1088,38	1,09
10	DD 8827 E	2	Solar	30,80	4080	1088,38	1,09
11	DD 9022 E	2	Solar	21,93	4080	1088,38	1,09
12	DD 9028 E	2	Solar	28,76	4080	1088,38	1,09
Total				**361,77**	**48.480**	**12932,52**	**12,93**

In the table above, you can see the total CO emissions$_2$ (Carbon Dioxide) produced under existing conditions is 12.93 tons/year with a total distance traveled of 361.77 km/day. This is due to the distance traveled by the waste transport vehicle.

The longer the route, the more CO emissions$_2$ (Carbon Dioxide) produced. Then it can also be seen from the vehicle classification in the form of age and vehicle maintenance. Waste transport vehicles are dominated by old vehicles and lack of maintenance. So CO emissions$_2$ (Carbon Dioxide) produced is greater.

Optimizing CO2 Emissions produced by Waste Transport Vehicles

To get CO emission values$_2$ (Carbon Dioxide) then the distance traveled by each vehicle is known from the results *network analysis* in GIS applications. Then the use of BBM (Fuel Oil) consumption is obtained from the average consumption of BBM (Fuel Oil) in existing conditions, namely 1.8 L/km, which means that 1 km of distance consumes 1.8 liters of BBM (Fuel Oil).

Then the average fuel consumption from existing conditions is multiplied by the total distance traveled by each vehicle. So it can produce the value of fuel consumption (fuel oil) for each waste transport vehicle.

After that, the value of energy consumption and CO emissions$_2$ (Carbon Dioxide) using the formula in equations 3 and 4 and the calculation results can be seen in attachment 3.

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Table 7: Optimization of CO Emissions2 (Carbon Dioxide) produced by Waste Transport Vehicles

No	Number of vehicles	Number of Rites	Fuel Type	Total Mileage	Fuel consumption	CO emissions2	
		(Rit/day)		(km/day)	Liters/year	kg/year	Tons/year
1	DD 8081 E	2	Solar	45,02	19448,64	5188,12	5,19
2	DD 8085 E	2	Solar	**61,45**	26546,40	7081,52	7,08
3	DD 8107 E	2	Solar	5,34	2306,88	615,38	0,62
4	DD 8108 E	2	Solar	57,05	24645,60	6574,46	6,57
5	DD 8109 E	2	Solar	21,10	9115,20	2431,57	2,43
6	DD 8117 E	2	Solar	47,83	20662,56	5511,94	5,51
7	DD 8122 E	2	Solar	58,45	25250,40	6735,80	6,74
8	DD 8124 E	2	Solar	27,90	12052,80	3215,20	3,22
9	DD 8183 E	2	Solar	38,17	16489,44	4398,72	4,40
10	DD 8827 E	2	Solar	30,31	13093,92	3492,93	3,50
11	DD 9022 E	2	Solar	25,81	11149,92	2974,35	2,97
12	DD 9028 E	2	Solar	24,71	10674,72	2847,59	2,85
Total				443,14	**191.436**	**51067,60**	**51,07**

You can see the table above produces total CO emissions2 (Carbon Dioxide) of 51.07 tons/year with a total distance of 443.14 km. This is assumed if each waste transport vehicle transports the entire waste to the waste source points. So the distance traveled by each vehicle will be further.

Comparison of CO Emissions2 Waste Transport Vehicle

In the graph above you can see CO emissions2 the largest (carbon dioxide) on the alternative route is produced by a vehicle with DD number 8085 E, namely 7.08 tons/year. This is because the longest distance is 61.45 km. Meanwhile, on the existing route CO emissions2 (Carbon Dioxide) is mostly produced by DD 8085 E and DD 8122 E, namely 1.22 tonnes/year. This is because the distance traveled on the DD 8085 E is 45.55 km/day, while the second largest on the DD 8122 E is 43.27 km/day. The second type of vehicle is the armroll truck type.

Comparison of CO Emissions2 and Volume of Waste Transported

In the graph above, car 3 (DD 8107 E) has a difference in CO2 emission values of -0.47 tonnes with a waste volume of 2.79 tonnes. The mines figure indicates a reduction in CO emissions2 because the volume of waste transported is also small and the distance traveled on the route is not that large, namely 0.88 km. Car 12 (DD 9028 E) had a difference in CO2 emission values of 1.76 tonnes, while the volume of waste transported decreased by -0.09 tonnes.

This is due to changes in routes taken to alternative routes so that waste transportation services are reduced. If compared to the existing route taken, it is the Minasatene axis road, Lanrayya village, kel. Biraeng, Bonto Manai Village, Kel. Langa-langa, Municipal Corporation. Pallateang, and Public Housing.

East Sandalwood. For alternative routes, Jalan Matahari, Jalan Bontoa Utara, Minasatene, Jalan Kelapa, Jalan Penas VII, Jalan Rumba, Jalan Wirakarya, Jalan Pramuka, Jalan Arung Kajuara, Jalan Pros Tonasa 2, and the Tabo-Tabo axis road. Because the alternative route serves the same 3 to 5 villages/subdistricts, the volume of waste transported shows mine results, which means that almost all of the waste can be transported.

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Other waste transportation cars have different values for CO emissions2 larger as the volume of waste transported increases. This shows that the route traveled is also quite far and the number of waste transportation services is also increasing.

Table 8: Recapitulation of Emissions, Distance and Volume of Waste Transporting Vehicles

No.	Number of vehicles	Transportation type	Emisi CO2 RE (ton)	Emisi CO2 RA (ton)	% difference	RE Mileage (km)	RA Mileage (km)	% difference	RE Transported Waste Volume (kg)	RA Transported Waste Volume (kg)	% difference
1	DD 8081 E	dump truck	0,90	5,19	4,29	35,29	45,02	9,73	1.253	16.933	15.680
2	DD 8085 E	arm roll	1,22	7,08	5,87	45,55	61,45	15,9	325	22.065	21.740
3	DD 8107 E	dump truck	1,09	0,62	-0,47	4,46	5,34	0,88	1.174	3.964	2.790
4	DD 8108 E	dump truck	0,96	6,57	5,61	38,65	57,05	18,4	2.496	16.164	13.668
5	DD 8109 E	dump truck	1,09	2,43	1,34	22,75	21,10	-1,65	1.721	11.088	9.367
6	DD 8117 E	dump truck	0,96	5,51	4,55	32,40	47,83	15,43	1.494	13.557	12.063
7	DD 8122 E	arm roll	1,22	6,74	5,52	43,27	58,45	15,18	1.899	13.512	11.613
8	DD 8124 E	arm roll	1,15	3,22	2,06	26,40	27,90	1,5	2.408	19.588	17.180
9	DD 8183 E	dump truck	1,09	4,40	3,31	31,51	38,17	6,66	1.046	16.882	15.836
10	DD 8827 E	arm roll	1,09	3,49	2,40	30,80	30,31	-0,49	1.703	24.924	23.221
11	DD 9022 E	arm roll	1,09	2,97	1,89	21,93	25,81	3,88	834	25.398	24.564
12	DD 9028 E	dump truck	1,09	2,85	1,76	28,76	24,71	-4,05	1.812	1.722	-90

Based on the table above, in existing conditions it can serve 17.57% of waste transportation with CO emissions2 (Carbon Dioxide) of 12.94 Tons/Year. Meanwhile, after optimizing waste transportation services, CO emissions were 68.31%2 (Carbon Dioxide) produced was 51.07 tons/year. The difference between waste transportation services is 50.74%, while the difference in CO emissions2 (Carbon Dioxide) produced was 38.13 tons/year. The increase in waste transportation services is due to the increase in population. The waste generated under existing conditions is 21,09 tons. Meanwhile, under optimization conditions it is 201,29 tonnes.

CO emissions2 the (carbon dioxide) produced affects waste transportation routes over longer distances. The distance in moving a waste source point to another waste source point with the truck running will affect fuel consumption. Vehicle age also influences CO emissions2 (Carbon Dioxide). If routine maintenance is not carried out, more emissions may be produced compared to carrying out routine maintenance on waste transportation activities. Fuel use also has an effect on producing CO emissions2 (Carbon Dioxide), namely fuel oil (diesel), is 48,480 liters/year in existing conditions, while in optimization conditions it is 191,436 liters/year.

CONCLUSION AND SUGGESTIONS

Results of network analysis show that optimizing waste transportation routes increases the number of routes and total distance traveled as well as fuel consumption. The percentage of waste transportation services increased drastically after optimization, but this was also accompanied by an increase in CO_2 emissions. Suggestions for government agencies include routine maintenance of waste vehicles, expanding waste service areas, increasing costs and vehicles, and collaborating with the community to reduce waste generation. It is recommended that future research take into account the costs and vehicle requirements to improve services to all sub-districts in Pangkajene Regency.

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