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Estimation and Mapping of Carbon Footprint in Transportation Sector (Case Study of Traffic Activities in East Karawang and West Karawang Sub-district)

Estimasi dan Pemetaan Jejak Karbon pada Sektor Transportasi (Studi Kasus Aktivitas Lalu Lintas di Kecamatan Karawang Timur dan Karawang Barat)

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Abstract

The high carbon emissions from the transportation sector, resulting from the growth of motor vehicles in East Karawang and West Karawang sub-districts, prompted the need for carbon footprint estimation and mapping. This study aims to estimate and map the carbon footprint of the transportation sector based on traffic activities in East Karawang and West Karawang sub-districts. Data collection was conducted through a questionnaire survey to 100 respondents representing eight villages in each sub-district, and supported by secondary data from relevant agencies. Information collected included vehicle type, type and amount of fuel used, and vehicle mileage. Emission calculations were conducted using the IPCC method by considering emission factors, net heating value (NCV), and fuel density. Results show that total emissions in East Karawang reached 121.03 tons of CO_2eq/year, highest in Warungbambu Village (28.93 tons), while West Karawang produced 126.08 tons of CO_2eq/year, highest in West Adiarsa (43.17 tons). The highest emissions generally come from the use of RON 90 fuel. Spatial analysis using QGIS shows the distribution of emissions varies between villages grouped into eight categories. This research can provide a spatial picture that can be used by the government for policies related to reducing emissions in areas that are still high in emissions.

Keywords: carbon footprint, CO_2 emission, east karawang, transportation, west karawang, QGIS.

INTRODUCTION

Increasing concentrations of greenhouse gases (GHGs) in the atmosphere are one of the main causes of climate change. GHGs such as Carbon Dioxide (CO_2), Methane (CH_4), Nitrogen Oxide (N_2O), and Chlorofluorocarbons (CFCs) can come from natural and human activities. Human activities such as land use change, agricultural activities, and the use of fossil fuels contribute greatly to the increase of GHGs (Yuliana, 2017).

In Indonesia, the transportation sector is a significant contributor to GHG emissions, mainly due to the high use of fossil-fueled motor vehicles. Emissions from vehicles account for around 60-85% of total transportation sector emissions (Ismiyati, 2014). The dominant gas produced is Carbon Dioxide (CO_2), the result of complete combustion of fuel (Sakinah, 2021). Large cities such as Karawang are areas prone to increased emissions due to traffic density (Santoso et al., 2020).

The use of electric cars in Indonesia increased by 9.3% in 2024, the dominance of fossil fuel vehicles is still very high, reaching 90.7% (Hall, D., et al., 2024). Based on BPS data in 2024, population growth in the last five years 2020-2024 increased by 7.3%, accompanied by an increase in the use of private vehicles by 1.85% (Novi, 2020).

The increase in the number of vehicles in Karawang has a direct impact on increasing CO_2 emissions, which negatively affects the environment. Based on classification, vehicles are divided into Heavy Vehicle (HV), Motorcycle (MC), and Light Vehicle (LV) (Heavy Vehicle National Law, 2021). Therefore, it is important to estimate and map the carbon footprint of the transportation sector in Karawang Regency.

This study aims to estimate and map CO_2 emissions based on fuel use, and present the spatial distribution of emissions in the region. The results are expected to provide policy recommendations for the local government in reducing the impact of transportation emissions on the environment.

METHOD

Time and Location of Research

The research was conducted in 2 sub-districts in Karawang Regency, namely West Karawang and East Karawang, with 8 villages each. The focus of the research was on calculating and mapping the carbon footprint of CO_2 emissions from transportation activities. The research took place from February to March 2025. An overview of the research location can be seen in Figure 1.

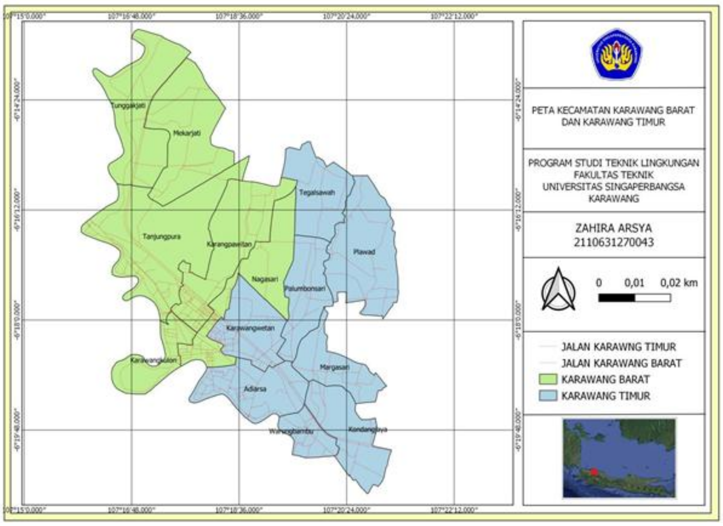


Figure 1. Administrative Map of East Karawang and West Karawang Sub-districts

Data Collection

This research was conducted with interview techniques using questionnaire tools, direct observation data in the field. The questionnaire data includes the type of vehicle, type of fuel, amount of fuel and respondents' daily mileage data (additional data).

Data Processing and Analysis

a. Calculation of CO_2 Emissions

The calculation of CO2 emissions is used with secondary carbon, primary carbon emissions and total emissions resulting from community interviews in East Karawang and West Karawang sub-districts using questionnaires. The number of respondents needed to represent East Karawang and West Karawang sub-districts was 100 respondents. The number was obtained from calculations based on the slovin method with Equation 1.

$$\eta = \frac{N}{1 + Na^2} \qquad (1)$$

were:

n = Number of Samples

N = Total population, namely the total number of vehicles in the study area

a = Limit of Error Tolerance (error tolerance) which is 10%

East Karawang and West Karawang sub-districts are the areas with the highest population concentration in Karawang Regency. Based on BPS 2024 data, the total population reached 328,790 people in 82,448 households. Assuming 4 people per family and a 10% error rate, the sample size was determined using the Slovin formula.

$$\eta = \frac{N}{1 + Na^2}$$

$$\eta = \frac{82.448}{1 + (82.448)(0.1)^2} = 99{,}88 = 100\ KK$$

After the calculation of the number of samples is obtained, then the number of samples is divided by each sub-district and can be calculated using the formula described by Sugiyono (2017) found in Equation 2. The number of respondents in East Karawang District can be seen in Table 1 and West Karawang District can be seen in Table 2.

$$ni = \frac{xi}{N}\ x\ n \quad (2)$$

were:

ni = Number of Samples in Each Sub-district / Village
xi = Number of Households in Each Sub-district/Village
N = Total Number of Households in the Study Area
n = Number of Samples in the Study Area

Table 1. Number of Respondents in East Karawang Sub-district

No	Villages	Respondent
1	Karawang Wetan	12
2	Palumbonsari	10
3	Kondangjaya	8
4	East Adiarsa	5
5	Warungbambu	4
6	Margasari	4
7	Plawad	4
8	Tegalsawah	3
	Total	51

Table 2. Number of Respondents in West Karawang Sub-district

No	Villages	Respondent
1	Karangpawitan	9
2	Karawang Kulon	6
3	West Adiarsa	6
4	Nagasari	6
5	Tunggakjati	6
6	Tanjungpura	6
7	Tanjungmekar	5
8	Merkarjati	5
	Total	49

Once the sample size was determined, data was collected from two sources: primary and secondary. Primary data included vehicle type, fuel type and amount, and distance traveled to calculate CO_2 emissions. Secondary data includes information such as population and other relevant data. In general, the calculation of CO2 emissions using the formula from IPCC (2006) can be seen in Equation 3.

$$E = DA\ X\ FE \quad (3)$$

were:

E = GHG Emissions (Ton)
DA = Activity Data (TJ)
FE = Emission Factor (Ton/TJ)

To calculate the DA value, you can use the formula based on the Ministry of Environment (2012) in Equation 4.

$$DA_{BBM} = F_{BBM}\ X\ \rho\ X\ NCV\ X\ 10^{-6} \quad (4)$$

Were:

DA_{BBM} = Activity Data (TJ)

F_{BBM} = Fuel Consumption in a Year (Kilo Liter)

ρ = Density of Fuel (Kg/m^3)

NCV = Net Calorific Value of Fuel (TJ/Ton)

Table 3. Emission Factor, NCV, and Density of Fuel Oil values

No	Fuel		Emission Factor (Ton/TJ)	Net Calorific Value (TJ/Gg)	Density of Fuel (Kg/m^3)
1	Gasoline	RON 90	69,29	44,61	770
2		RON 92	69,04	44,61	770
3		RON 98	68,91	44,62	770
4	Diesel	CN 48	73,28	43,27	880
5		CN 51	72,93	43,43	880
6		CN 53	72,85	43,55	860

b. CO_2 emission Distribution Mapping with QGIS

After the calculations were completed, spatial analysis was conducted using QGIS to map carbon emissions from traffic in each neighborhood in East Karawang and West Karawang. QGIS allows visualization of GHG emissions distribution based on vehicle data, fuel consumption, and emission factors. The spatial factors analyzed include the type of vehicle and the amount of emissions in each sub-district.

Mapping was done through several methods:

1. Attribute digitization to insert emission data into the layer
2. Spatial representation to show the distribution of emissions
3. Labeling to display location information and emission values
4. Map visualization to show overall emission variation.

Figure 2 (a) shows the types of vehicles used by the community in East Karawang Sub-district. Based on Figure 2, it is found that the number of motorized vehicles in East Karawang Sub-district is 91 units, consisting of 72 units of Category L (two-wheelers), 16 units of Category M (four-wheelers), 3 units of Category N (goods carriers), and there are no Category O vehicles (trailers) so they are not included in the visualization on the graph. The highest number of vehicles is found in Village Karawang Wetan and the lowest number of vehicles is found in Village Tegalsawah.

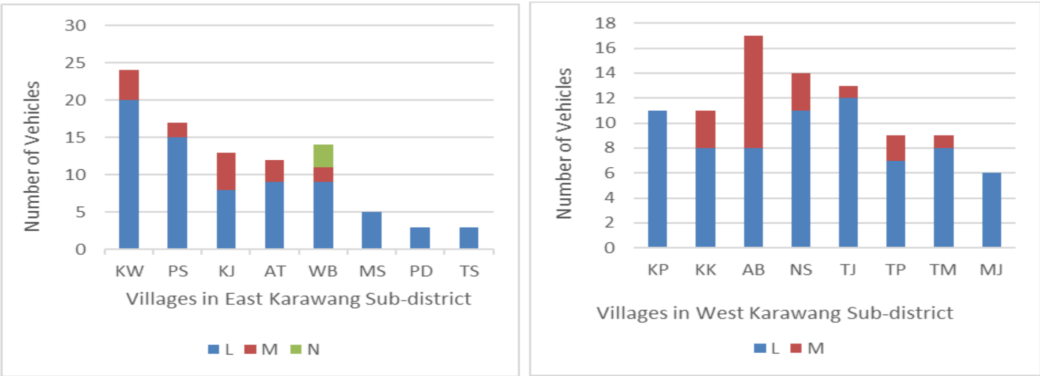
RESULT AND DISCUSSION

Characteristics of Vehicle Type, Type and Amount of Fuel and Mileage Used

The carbon footprint of transportation sector traffic activities contributes significantly to CO_2 emissions, one of the major greenhouse gases. These emissions come from the combustion of fossil fuels and other human activities such as deforestation, which cause an increase in CO_2 concentrations in the atmosphere and a rise in global temperatures each year (Wiratama et al., 2016). Factors that influence the amount of emissions include the type of vehicle, the type and amount of fuel, and the distance traveled.

a. Type of Motor Vehicle

Vehicle type information includes L, M, N, and O categories, showing both the number and variety of motor vehicles used in daily transportation activities in East Karawang (Figure 2 (a)) and West Karawang (Figure 2 (b)) sub-districts.



(a) (b)

Figure 2. Type of Motorized Vehicle (a) East Karawang Sub-district (b) West Karawang Sub-district

Meanwhile, Figure 2 (b) shows the types of vehicles used by the community in West Karawang Sub-district. Based on Figure 3, the number of motorized vehicles in West Karawang Sub-district is 90 units, consisting of 71 units of Category L (two-wheelers) and 19 units of Category M (four-wheelers), with no vehicles in Categories N and O so they are not included in the graph. With the highest number in West Adiarsa Village and the lowest in Mekarjati Village. This data shows the dominance of two-wheeled vehicles in both sub-districts, although there are slight differences in the distribution of other categories.

The increase in the number of motorized vehicles every year adds about 7 million motorized vehicles, so that in 2016 the number is estimated to reach 125 million units, about 10 to 15% of which are cars that contribute to environmental pollution due to exhaust emissions (Oktaviastuti et al., 2017). The percentage of motorcycles is much greater than cars, because motorcycles are considered a more practical mode of transportation and are owned by almost all levels of society (Kasman, M., et al., 2020).

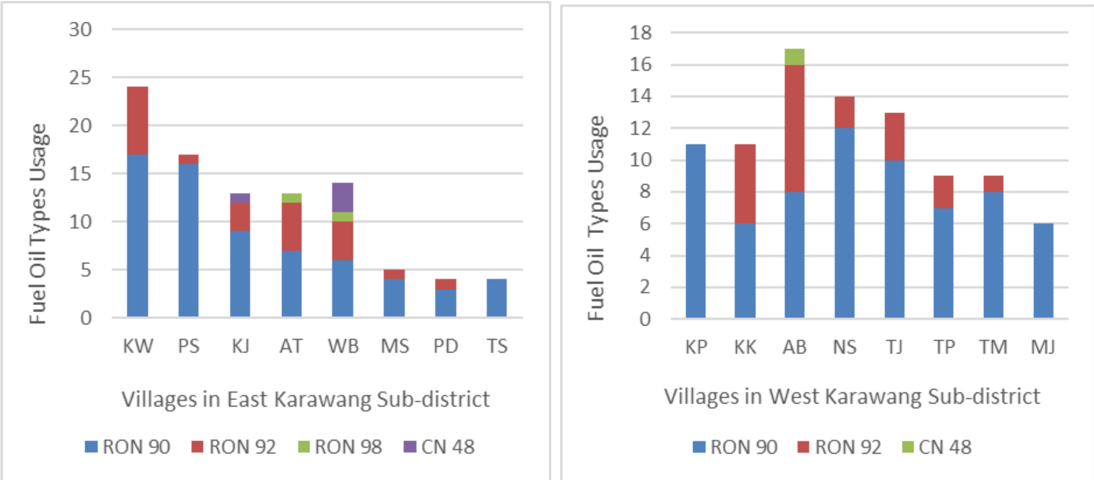
b. Type of Fuel Used

Information on the type of fuel used by motorized vehicles in all villages within East Karawang and West Karawang sub-districts. The data provides an overview of fuel use preferences in each villages, both fossil fuels such as gasoline and diesel.

Figure 3 (a) shows the type of fuel used by people in East Karawang Sub-district. Based on Figure 4, East Karawang Sub-district has 94 fuel users based on the number of vehicles per household. The majority use RON 90 with 66 users (around 70%), followed by RON 92 with 22 users, and RON 98 is only used by 2 users. Meanwhile, CN 48 diesel fuel was used by 4 users. No users were found for CN 51 or CN 53, so they were not included in the graph visualization. The highest vehicle type is found in Karawang Wetan urban village and the lowest in Tegalsawah urban village. This data shows the dominant use of low-octane gasoline in community transportation activities.

Figure 3 (b) shows the type of fuel used by the community in West Karawang Sub-district. Based on Figure 5, there are 90 fuel users in West Karawang Sub-district. The majority use RON 90 as many as 68 users, reflecting the dominance of low octane fuels that are more affordable and suitable for community vehicles. A total of 21 users choose RON 92, for diesel, only 1 user uses CN 48, while there are no users of RON 98, CN 51 or CN 53, so they are not included in the graph.

Most fuel consumers consider the price and quantity of fuel they get when buying at gas stations. Few consumers consider the impact of using fuel with a low octane number (RON). In fact, the choice of fuel type greatly affects the level of environmental pollution and fuel consumption efficiency (Pomantow *et al*., 2019).



(a) (b)

Figure 3. Fuel Oil Types Usage (a) East Karawang Sub-district (b) West Karawang Sub-district

a. Amount of Fuel Used

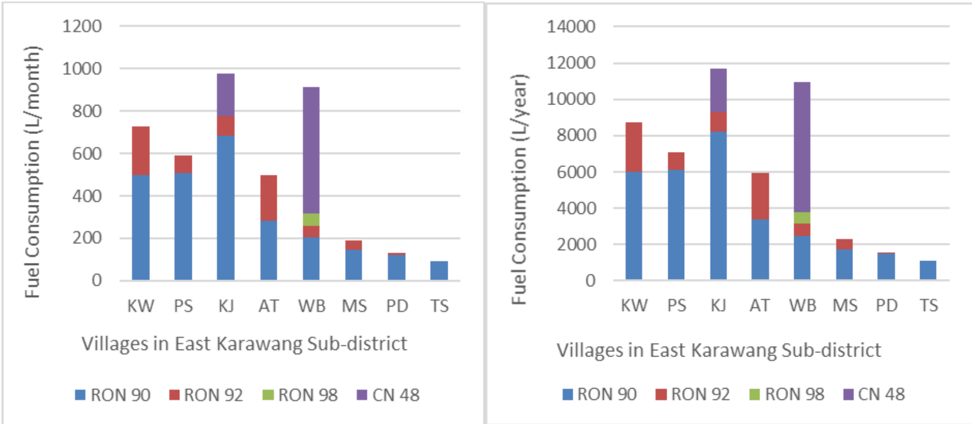
Fuel usage data based on octane number (RON 90, 92, 98) and cetane (CN 48, 51, 53) shows the distribution of public consumption according to the technical characteristics of the fuel. RON measures the quality of gasoline, while CN is for diesel. This information helps understand user preferences and their impact on emissions. Figure 4 (a) (East Karawang) and Figure 5 (a) (West Karawang) illustrate the consumption of fuel used in units of L/month. While Figure 4 (b) (East Karawang) and Figure 5 (b) (West Karawang) illustrate fuel consumption in units of L/Year.

Based on Figure 4 (a), information on fuel consumption in units of L/month in East Karawang Subdistrict is presented, the results are dominated by RON 90 at 2,505 L/month, followed by CN 48 at 794 L/month, RON 92 at 729 L/month, and RON 98 at 55 L/month, while CN 51 and CN 53 are not used and are not shown on the graph. Continued with fuel usage in units of L/year presented in Figure 4 (b) shows a similar trend, with RON 90 reaching 30,060 L/year, CN 48 amounting to 9,529 L/year, RON 92 totaling 8,749 L/year, and RON 98 only 657 L/year. Meanwhile, CN 51 and CN 53 are not shown on the graph. The highest fuel consumption is found in Kondangjaya and Warung Bamboo villages, while the lowest consumption is found in Tegalsawah village.

Fuel consumption data in East Karawang Sub-district shows the dominance of RON 90 use by private vehicles for daily activities, followed by RON 92 and RON 98, while CN 48 is generally used by category N vehicles for long-distance transportation. Thus, CN 48 cannot be compared directly with RON-type fuels.

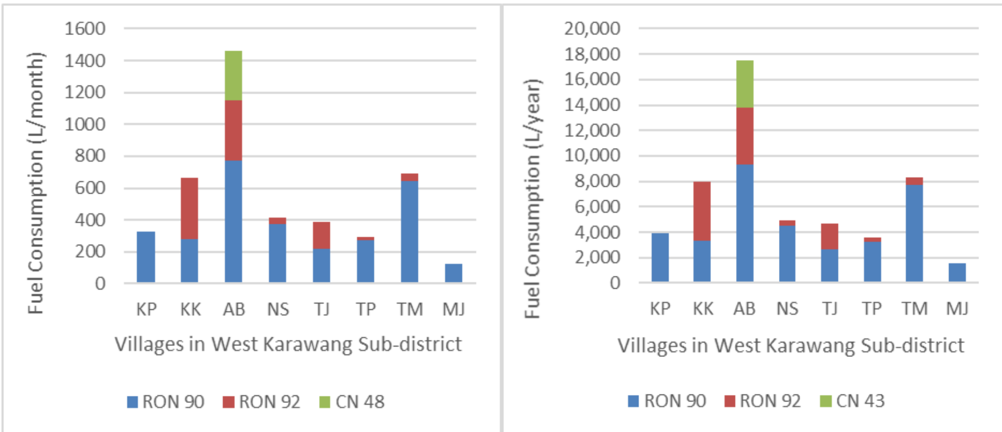
Based on Figure 5 (a), it is presented that fuel consumption in West Karawang Sub-district in months is dominated by RON 90 of 5,012 L/month, followed by RON 92 of 1,044 L/month, CN 48 only recorded 309 L/month, while RON 98, CN 51, and CN 53 are not used so they are not included in the graph. Continued with fuel usage in units of L/year. Figure 5 (b) shows a similar pattern, with RON 90 reaching 36,144L/year, RON 92 at 12,530 L/year, and CN 48 at 3,706 L/year. This data confirms that RON 90 dominates fuel use due to its suitability to the needs of vehicles and the economic conditions of the community.

Pertalite or RON 90 fuel is widely used because it is cheaper than RON 92 and RON 98, making it the highest selling fuel in Indonesia. This shows that most people choose fuel based on economic considerations, not engine specifications (Berto *et al*., 2022).



(a) (b)

Figure 4. Fuel Consumption (a) East Karawang Sub-district (L/month) (b) East Karawang Sub-district (L/year)



(a) (b)

Figure 5. Fuel Consumption (a) East Karawang Sub-district (L/month) (b) East Karawang Sub-district (L/year)

a. Distance Traveled by Each Motor Vehicle

Table 4 & Table 5 show the average vehicle mileage in East Karawang and West Karawang sub-districts per Km/month. The information is used as supporting data to validate with fuel usage.

Based on Table 4, the total vehicle mileage per month in East Karawang sub-district reached 47,610 Km/month for category L, 20,340 Km/month for category M, and 4,500 Km/month for category N, while category O showed no activity. The highest mileage was recorded in Village Karawang Wetan, but this does not directly reflect the amount of emissions, as emissions are more influenced by fuel type and consumption, where low-octane fuel produces higher emissions.

Table 4. Travel Distance in East Karawang Sub-district

Villages	Distance Traveled (Km/month)			
	Category L	Category M	Category N	Category O
Karawang Wetan	12,000	4,950		
Palumbonsari	9,270	1,950		
Kondangjaya	4,470	7,740		
East Adiarsa	5,520	2,250		
Warungbambu	3,360	2,250	4,500	
Margasari	4,080			
Plawad	1,350	1,200		
Tegalsawah	2,760			
Total	47,610	20,340	4,500	

Table 4. Travel Distance in West Karawang Sub-district

Villages	Travel Distance (Km/month)			
	Category L	Category M	Category N	Category O
Karangpawitan	4,530			
Karawang Kulon	3,360	2,400		
West Adiarsa	3,660	11,400		
Nagasari	4,500	1,050		
Tunggakjati	4,920	600		
Tanjungpura	4,380	1,710		
Tanjungmekar	7,170	2,400		
Mekarjati	1,830			
Total	34,350	19,560		

Based on Table 5, the total vehicle miles traveled in West Karawang Sub-district reached 34,350 Km/month for category L and 19,560 Km/month for category M, without vehicle activity in categories N and O. Village Adiarsa Barat recorded the highest mileage for category M at 11,400 Km/month, while Village Mekarjati recorded only 1,830 Km/month, reflecting differences in mobility patterns.

CO_2 Emissions Calculation

The calculation of carbon emissions from transportation activities is carried out by processing annual fuel consumption data in each village, multiplied by the net calorific value (NCV), the emission factor of each fuel, and the global warming potential (GWP), to estimate CO_2e emissions resulting from fuel combustion.

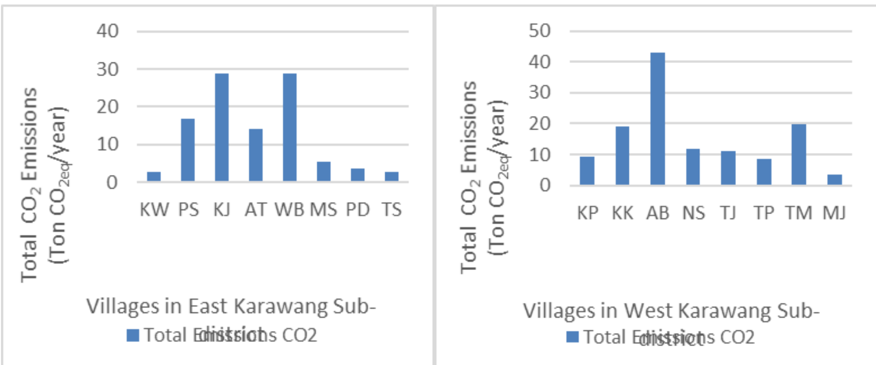


Figure 6. Total CO_2 Emissions (Ton CO_{2eq}/year) (a) East Karawang Sub-district (b) West Karawang Sub-district

Figure 6 (a) shows that Village Kondangjaya and Warungbambu are the largest contributors to carbon emissions due to high vehicle ownership and use, while emissions in Tegalsawah are lower due to the small number of households and minimal mobility activities, supported by the relatively calm condition of the area and low economic activity.

Based on Figure 6 (b), Village Adiarsa Barat is the highest contributor to carbon emissions in West Karawang Sub-district due to high daily transportation activities and its strategic location near the city center, while Village Mekarjati records low emissions due to the small number of household heads, low mobility, and limited access to private vehicles.

Emissions CO_2 Distribution Mapping Using QGIS

After the carbon emission data and calculations were collected, the carbon footprint of East and West Karawang sub-districts was mapped using QGIS, with the emissions of each sub-district grouped into 8 categories to facilitate identification of high or low emission areas, as listed in Table 6.

Table 5. Grouping Emissions by Color

Color	Emission Range (ton CO_2eq/year)	Emission (ton CO_2eq/year)	Villages
	0-6	2.57	Tegalsawah
		3.60	Mekarjati
		3.71	Plawad
		5.44	Margasari
	6-12	8.44	Tanjungpura
		9.25	Karangpawitan
		11.11	Tunggakjati
		11.75	Nagasari
	12-18	14.14	East Adiarsa
		16.90	Palumbonsari
	18-24	19.02	Karawang Kulon
		19.75	Tanjungmekar
		20.78	Karawang Wetan
	24-30	28.83	Kondangjaya
		28.98	Warungbambu
	30-36	-	-
	36-42	-	-
	42-49	43.17	West Adiarsa

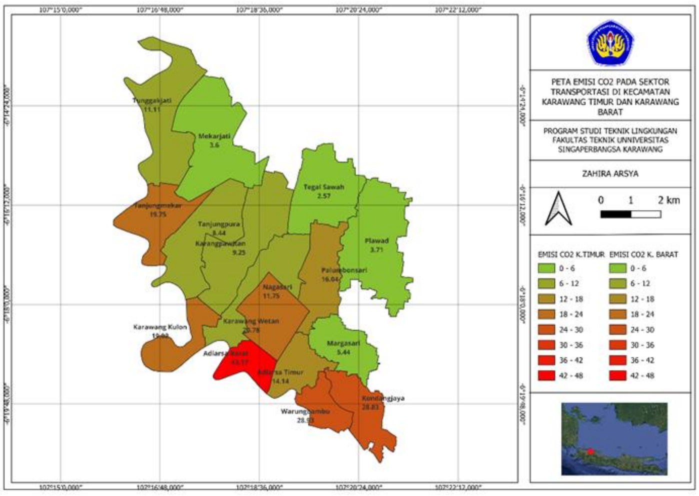


Figure 7. Map of CO2 Emissions in East Karawang and West Karawang Sub-districts

Based on Table 6 and Figure 7, the distribution of carbon emissions in East and West Karawang Subdistricts is grouped into emission ranges and visualized with color gradations in QGIS. Range 1 is for low emissions (0-6 tons CO_2eq/year) such as Tegalsawah, Mekarjati, Plawad, and Margasari. Reach 2 (6-12 tons CO_2eq/year) for Tanjungpura, Karangpawitan, Tunggakjati and Nagasari. Reach 3 (12-18 tons CO_2eq/year) for East Adiarsa and Palumbonsari. Reach 4 (18-24 tons CO_2eq/year) for Karawang Kulon, Tanjungmekar and Karawang Wetan. Reach 5 (24-30 tons CO_2eq/year) for Kondangjaya and Warungbambu. Reach 6 (30-36 tons CO_2eq/year) has not been filled. Reach 7 (36-42 tons CO_2eq/year) has not been filled. Reach 8 (42-48 tons CO_2eq/year) for West Adiarsa. This grouping makes it easier to identify high and low emission areas.

CONCLUSIONS AND SUGGESTIONS

Total carbon emissions from the transportation sector in East Karawang amounted to 121.03 tons CO_2eq/year, the highest in Warungbambu (28.93 tons), while West Karawang reached 126.08 tons CO_2eq/year, the highest in West Adiarsa (43.17 tons), making it the region with higher emissions. Mapping reveals variations between neighborhoods: Reach 1 (0-6 tons of CO_2eq/year) such as Tegalsawah, Mekarjati, Plawad and Margasari. Reach 2 (6-12 tons of CO_2eq/year) for Tanjungpura, Karangpawitan, Tunggakjati and Nagasari. Reach 3 (12-18 tons CO_2eq/year) for East Adiarsa and Palumbonsari. Reach 4 (18-24 tons CO_2eq/year) for Karawang Kulon, Tanjungmekar and Karawang Wetan. Reach 5 (24-30 tons CO_2eq/year) for Kondangjaya and Warungbambu. Reach 6 (30-36 tons CO_2eq/year) has no emissions. Reach 7 (36-42 tons CO_2eq/year) no emissions. Reach 8 (42-48 tons CO_2eq/year) for West Adiarsa. It is recommended that similar research be conducted in other areas in Karawang Regency and respondents be selected in more detail based on economic characteristics for more representative results.

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