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ESTIMATION OF CARBON DIOXIDE EMISSION IN THE TRANSPORTATION SECTOR ON PRIMARY ARTERIALROADS IN WONOKROMO DISTRICT, SURABAYA BEFORE AND AFTER COVID-19

(Anggaran Pelepasan Gas Karbon Dioksida Bagi Sektor Pengangkutan di Jalan Utama Daerah Wonokromo Kota Surabaya Sebelum dan Selepas Covid-19)

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Abstract

This research aims to determine the number of motorized vehicles of the road transportation sector at primary arterial roads inWonokromo District before and after COVID-19, the estimated amount of emission produced by motorized vehicles before and after COVID-19 and the correlation between the distribution of the amount and the types of motorized vehicles and the estimated amount of carbon dioxide (CO2) emission. Data collection for determining the amount and type of motorized vehicles was conducted at Jalan Stasiun Wonokromo, Jalan Bung Tomo and Jalan Raya Ngagel. Data collection was conducted in the morning (06.00-08.00 a.m.), afternoon (11.00 a.m. – 01.00 p.m.) and evening (04.00-06.00 p.m.). This study utilizes the IPCC method to determine the concentration of CO2 while implementing the IPCC formula in travel distance approach and the idle emission formula in fuel consumption approach. The estimated amount of CO2 emission load is decreased due to COVID-19 by 44% at Jalan Stasiun Wonokromo, by 62% at Jalan Bung Tomo and by 34% at Jalan Raya Ngagel. The total number of motorized vehicles correlates to the estimated amount of CO2 emission load where there is an increase in number of motorizedvehicles there will be an increase in the estimated amount of CO2 emission load as well.

Keywords: before and after COVID-19, carbon dioxide, idle emission, motorized vehicles, primary arterial roads

Abstrak

Kajian ini bertujuan untuk mengetahui jumlah kendaraan bermotor berdasarkan jenisnya di jalan utama daerah Wonokromo sebelum dan selepas COVID-19, anggaran beban pelepasan yang dihasilkan oleh kenderaan bermotor sebelum dan selepas COVID-19 dan mengetahui hubungan antara taburan jumlah dan jenis kendaraan bermotor dengan anggaran pelepasan gas karbon dioksida (CO2). Pengambilan data berupa jumlah dan jenis kendaraan bermotor dilakukan di Jalan Stasiun Wonokromo, Jalan Bung Tomo dan Jalan Raya Ngagel. Pengambilan data dilakukan pada pagi (06.00-08.00 WIB), tengahari (11.00-13.00 WIB) dan petang (16.00-18.00). Penelitian ini menggunakan kaedah pengiraan kepekatan CO2 dengan pendekatan jarak tempuh kenderaan menggunakan formula IPCC dan pengunaan bahan bakar menggunakan formula pelepasan terbiar. Pandemik COVID-19 menyebabkan terjadinya penurunan beban pelepasan CO2. Jalan Stasiun Wonokromo mengalami penurunan sehingga 44%, Jalan Bung Tomo pada 62% dan Jalan Raya Ngagel pada 34%. Korelasi antara jumlah kenderaan dengan anggaran pelepasan gas CO2 dipercayai semakin tinggi jumlah kenderaan maka semakin tinggi beban pelepasan CO2 berlaku.

Kata kunci: sebelum dan selepas COVID-19, karbon dioksida, pelepasan terbiar, kenderaan bermotor, jalan utama

Introduction

The increasing use of energy from fossil fuels for various human activities especially in industrial processes, transportation, and forest-clearing activities has led to increased greenhouse-gas emissions. The transportation sector plays a major role in air pollution through motorized-vehicle emissions. Motorized-vehicle emissions globally contribute 60% to air pollution, wherein 25% is made up of CO_2, 50% of NOx, and 25% of other gases[1]. CO_2 is also the main cause of the increase in the Earth's temperature, and the effect is bound to continue. The 2007 Global Climate Assessment showed that CO_2 has a radiative forcing (RF) value of 1.68 W/m^2. CO_2 has the largest positive RF value of all greenhouse gases produced by human activities, so CO_2 plays the largest role in global warming. A positive RF value represents an average increase in surface temperature caused by a gas, and a negative one indicates a decrease in temperature [2]. The increase in the number of motorized vehicles in the city of Surabaya has affected the amount of gas emissions produced, thereby contributing to climate change and global warming. The consumption of fossil fuels in metropolitan cities tends to be high owing to high levels of population, mobility, and increased urban-transportation activities. The increase in urban-transportation activities in Indonesia is triggered by an increase in the ownership and use of private vehicles [3].

Materials and Methods

Based on the Technical Guidelines for Deconcentration of Mobile Source Air Pollution Control, the areas of study are three primary arterial roads in the city. The sampling was a one-time sampling. Sampling shall be conducted on working days and weekend; thus Monday, Tuesday, Saturday and Sunday were selected as representatives [4]. Accordingly, Jalan Stasiun Wonokromo, Jalan Bung Tomo, and Jalan Raya Ngagel were selected. Eleven sampling points on the three roads were chosen, as shown in Figures 2 - 4.

Primary data collection

The primary data needed for this study were the number of vehicles, vehicle types, vehicle idling time, and travel distance. The number of vehicles was obtained by traffic counting at the predetermined sampling points before COVID-19 and by using CCTV footages after COVID-19. Traffic counting was conducted for a week after COVID-19 because traffic counting through CCTV footages did not need to consider volunteer to help onthe road. Traffic counting was conducted at peak hours in the morning (06.00–08.00 a.m.), afternoon (11.00 a.m.–01.00 p.m.) and evening (04.00–06.00 p.m.). Traffic counting was performed using a manual hand counter.Vehicle idling time was the duration of vehicles stopping and in idle condition at a red light. Travel distance wasthe length of road segments which differs based on inlet and outlet points of vehicles on each road. The length of road segments and idling time at each sampling point are listed in Table 1.

Secondary data collection

The secondary data needed for this study were emission factor (Table 2) [5], fuel economy in running condition(Table 3) [5], fuel economy in idle condition (Table 3) [6], and fuel density. Fuel density in this study included gasoline (0.737 kg/m$^{3)}$ and diesel (0.82 kg/m^{3}).

Figure 1. Primary arterial roads in Wonokromo District

Directory:

: Primary Arterial Roads in Wonokromo District

1. : Jalan Diponegoro
2. : Jalan Raya Ngagel
3. : Jalan Bung Tomo
4. : Jalan Upa Jiwa
5. : Jalan Ratna
6. : Jalan Wonokromo
7. : Jalan Stasiun Wonokrom

Figure 2. Sampling points in Jalan Stasiun Wonokromo

Figure 3. Sampling points in Jalan Bung Tomo

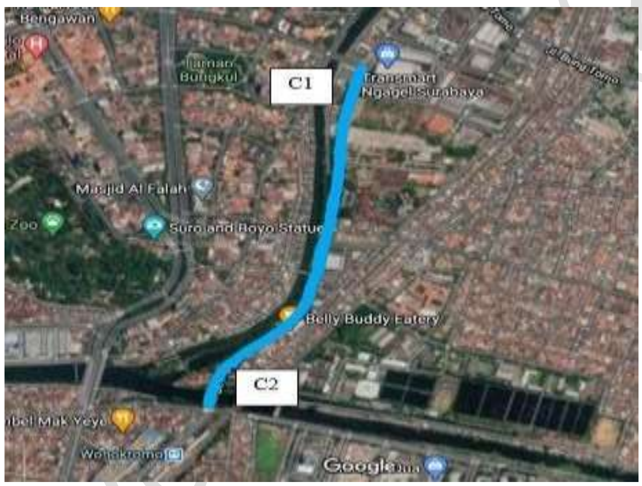

Figure 4. Sampling points in Jalan Raya Ngagel

Table 1. Length of road segments and idling time at each sampling point

Street Name	Sampling Point	Length of Road Segment (km)	Idling Time (h)
Stasiun Wonokromo	A1	0.352	0.0167
	A2	0.517	0.0250
	A3	0.169	-
Bung Tomo	B1	0.083	0.0167
	B2	0.083	-
	B3	0.226	0.0250
	B4	0.226	0.0250
Bung Tomo	B5	0.408	-
	B6	0.408	-
Raya Ngagel	C1	1.120	0.0167
	C2	1.120	0.0200

Table 2. Emission factor of motorized vehicles in Indonesian cities

	Type of Vehicle	**CO (g/km)**	**HC (g/km)**	**NOx (g/km)**	**PM10 (g/km)**	**CO2 (g/kg fuel)**	**SO2 (g/km)**
1.	Motorcycle	14	5.9	0.29	0.24	3180	0.008
2.	Gasoline-fueled van/minibus	40	4	2	0.01	3180	0.026
3.	Diesel-fueledvan/minibus	2.8	0.2	3.5	0.53	3172	0.44
4.	Bus	11	1.3	11.9	1.4	3172	0.93
5.	Truck	8.4	1.8	17.7	1.4	3172	0.82
6.	Angkutan kota (angkot)	43.1	5.08	2.1	0.006	3180	0.029
7.	Taxi	55.3	5.6	2.8	0.008	3180	0.025
8.	Pick-up truck	31.8	3.5	2	0.026	3178	0.13
9.	Jeep	36.7	3.86	2.36	0.039	3178	0.145
10.	Sedan	33.8	3.7	1.9	0.004	3180	0.023

Table 3. Fuel economy in running condition

No.	**Type of Vehicle**	**km/liter**
1.	Sedan	9.8
2.	Van/minibus	8
3.	Taxi	8.7
4.	Angkot	7.5
5.	Micro and medium bus	4
6.	Large bus	3.5
7.	Pick-up truck	8.5
8.	Truck with 2 sets of axles	4.4
9.	Truck with 3 sets of axles	4
10.	Jeep	8
11.	Motorcycle	28

Table 4. Fuel economy in idle condition

	Type of Vehicle	**mL/10 min**	**L/h**
1.	Sedan	88.0	0.528
2.	Van/minibus	88.0	0.528
3.	Taxi	88.0	0.528
4.	Angkot	88.0	0.528
5.	Micro and medium bus	153.1	0.919
6.	Large bus	108.2	0.649
7.	Pick-up truck	88.0	0.528
8.	Truck with 2 sets of axles	167.0	1.002
9.	Truck with 3 sets of axles	419.3	2.516
10.	Jeep	100.0	0.600
11.	Motorcycle	22.8	0.137

Emission load calculation

CO_2 emissions for motorized vehicles while traveling was calculated using a modified equation from the Intergovernmental Panel on Climate Change [7], as shown in Equation 1.

EF is the emission factor of CO_2 (g/kg-fuel), FE is fuel economy (km/l), TD travel distance or road length (km), AV is the number of vehicles per vehicle type (unit), and fuel density in this study included gasoline and diesel (kg/m^3).

CO_2 emissions produced by motorized vehicles in idle condition were calculated using Equations 2 and 3 [8].

Idle emissions are emissions in idle condition (g/day), idle-fuel use is fuel used in idle time (l/day), GHG emission factor (g/L), AV is the number of vehicles per vehicle type (unit), and fuel density in this study includedgasoline and diesel (kg/m^3).

Statistical analysis

The data obtained were tested statistically with the Kolmogorov-Smirnov test and the Spearman correlation test using the Statistical Package for the Social Sciences (SPSS) application. The Kolmogorov-Smirnov test was conducted to determine whether the research data were normally distributed or not. The data was then examined by the Spearman correlation test because it was not normally distributed.

$$\text{Emission (tonnes/year)} = \text{EF} \times (1 / \text{FE}) \times \text{TD} \times \text{AV} \times \text{fuel density} \times 10^{-6} \times 365 \text{ (day/year)} \quad (1)$$

$$\text{Idle-fuel use} = (\text{idle-fuel flow}) \times (\text{idle time per day}) \quad (2)$$

$$\text{Idle emissions} = (\text{idle-fuel use}) \times (\text{GHG emission factor}) \times \text{AV} \times \text{fuel density} \quad (3)$$

Results and Discussion

Vehicle volume and composition

Vehicle volume on Jalan Stasiun Wonokromo, Jalan Bung Tomo, and Jalan Raya Ngagel before COVID-19 is shown in Figures 5 - 7.

Vehicle volume before COVID-19 was 296,292 units on Jalan Stasiun Wonokromo, 346,740 units on Jalan BungTomo, and 561,463 units on Jalan Raya Ngagel. Vehicle activity was higher during weekdays compared to weekend. High vehicle activity on weekdays was related to community activities, such as work and academic activities [9, 10]. Vehicle volume on Jalan Stasiun Wonokromo, Jalan Bung Tomo, and Jalan Raya Ngagel after COVID-19 is shown in Figures 8 - 10.

Vehicle volume after COVID-19 was 551,716 units on Jalan Stasiun Wonokromo, 449,495 units on Jalan BungTomo, and 424,068 units on Jalan Raya Ngagel. The City Government of Surabaya began implementing large- scale social restrictions on April 28, 2020. This regulation was implemented as an effort to prevent the spread ofCOVID-19. Restrictions were made on activities outside the home and modes of transportation [11]. Vehicle composition on Jalan Stasiun Wonokromo, Jalan Bung Tomo, and Jalan Jalan Raya Ngagel after COVID-19 is shown in Figures 11 - 13.

The number of vehicles on the three roads was dominated by motorcycle, with percentages of 83%, 74%, and 82%, respectively. The vehicle with the second largest percentage was gasoline-fueled van/minibuse with a percentage of 12% on Jalan Wonokromo Station, 21% on Jalan Bung Tomo, and 13% Jalan Raya Ngagel. The lowest number of vehicles on the three roads was truck with three sets of axle.

Estimated CO_2 emission

Estimated CO_2 emission on Jalan Stasiun Wonokromo, Jalan Bung Tomo, and Jalan Raya Ngagel before and after COVID-19 is shown in Figures 14 - 16.

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Estimated CO_2 emission on Jalan Stasiun Wonokromo, Jalan Bung Tomo, and Jalan Raya Ngagel before and after COVID-19 is shown in Figures 14 - 16.

Estimated CO_2 emission before COVID-19 was 5,259 kg/year on Jalan Stasiun Wonokromo, 6,668 kg/year on Jalan Bung Tomo, and 8,202 kg/year on Jalan Raya Ngagel. Figures 13–15 show decreased CO_2 emission on thethree roads owing to the COVID-19 COVID-19. Estimated CO_2 emission decreased by 44% on Jalan Stasiun Wonokromo, by 62% on Jalan Bung Tomo, and by 34% on Jalan Raya Ngagel. The estimated CO_2 emission after the COVID-19 was 2,945 kg/year on Jalan Stasiun Wonokromo, 2,478 kg/year on Jalan Bung Tomo, and 5,402 kg/year on Jalan Raya Ngagel.

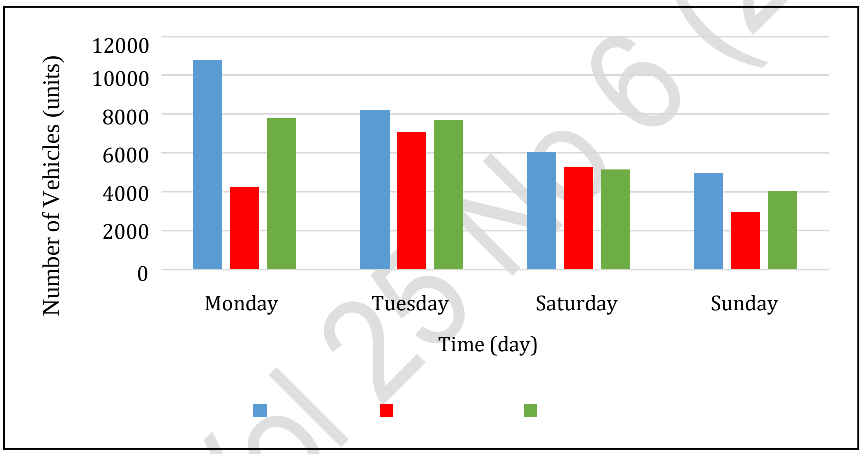

Figure 5. Vehicle volume on Jalan Stasiun Wonokromo before COVID-19

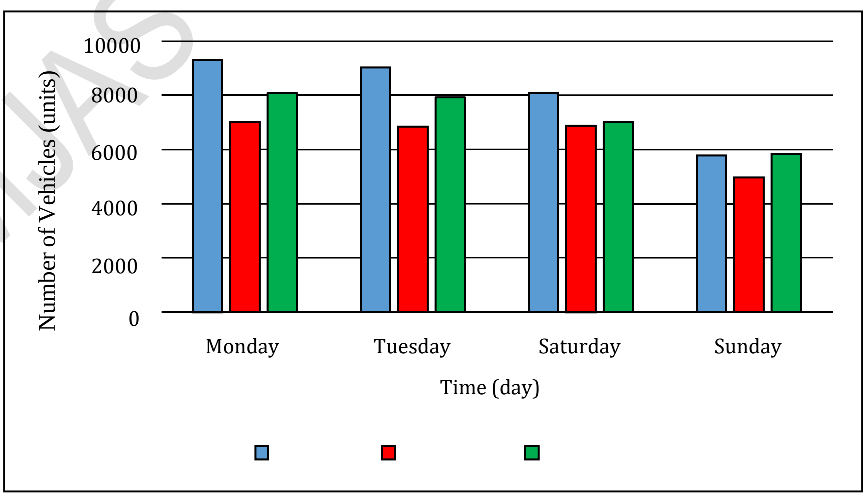

Figure 6. Vehicle volume on Jalan Bung Tomo before COVID-19

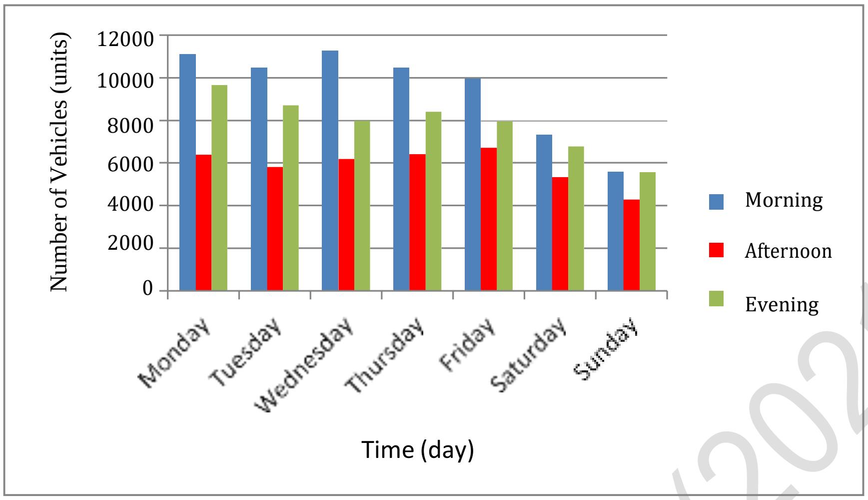

Figure 7. Vehicle volume on Jalan Raya Ngagel before COVID-19

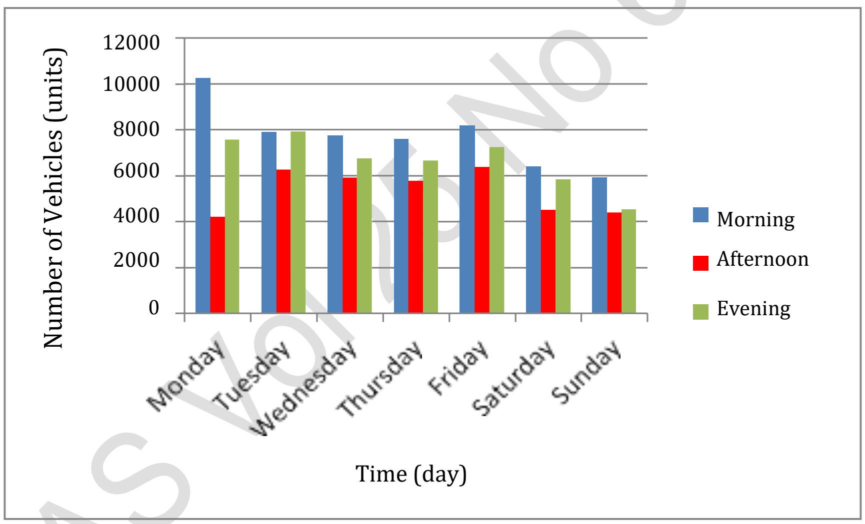

Figure 8. Vehicle volume on Jalan Raya Ngagel after COVID-19

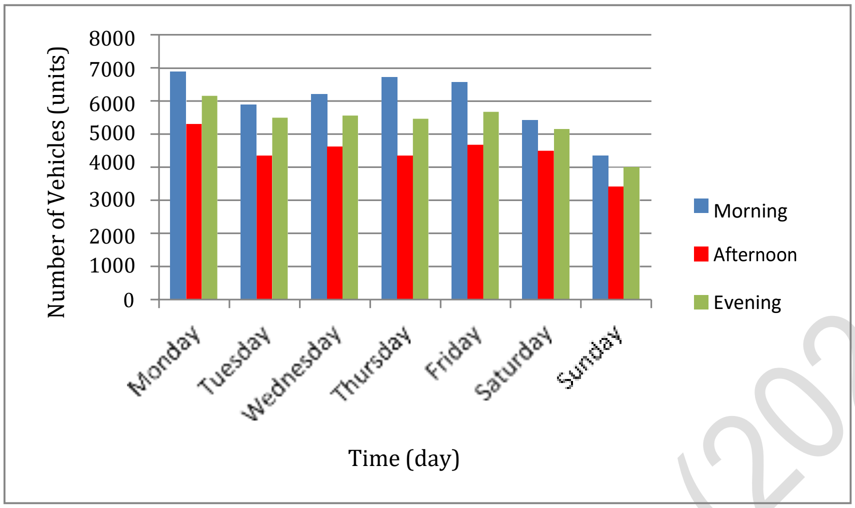

Figure 9. Vehicle volume on Jalan Bung Tomo after COVID-19

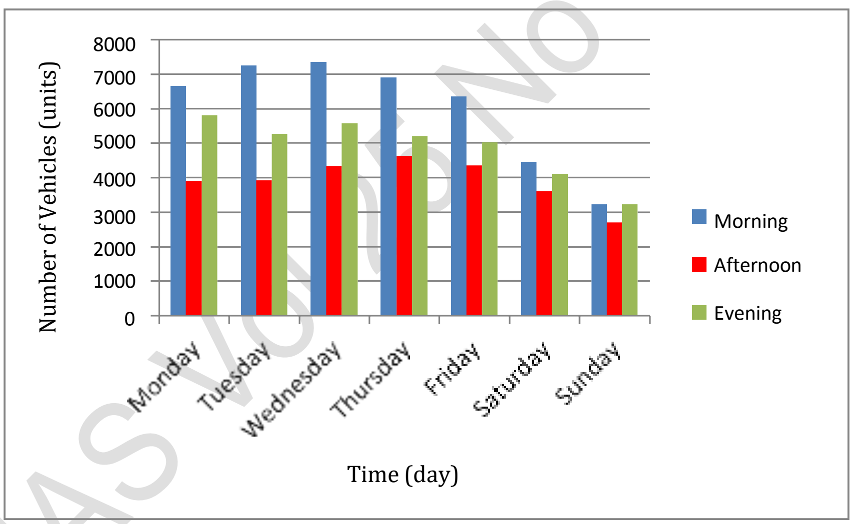

Figure 10. Vehicle volume on Jalan Bung Tomo after COVID-19

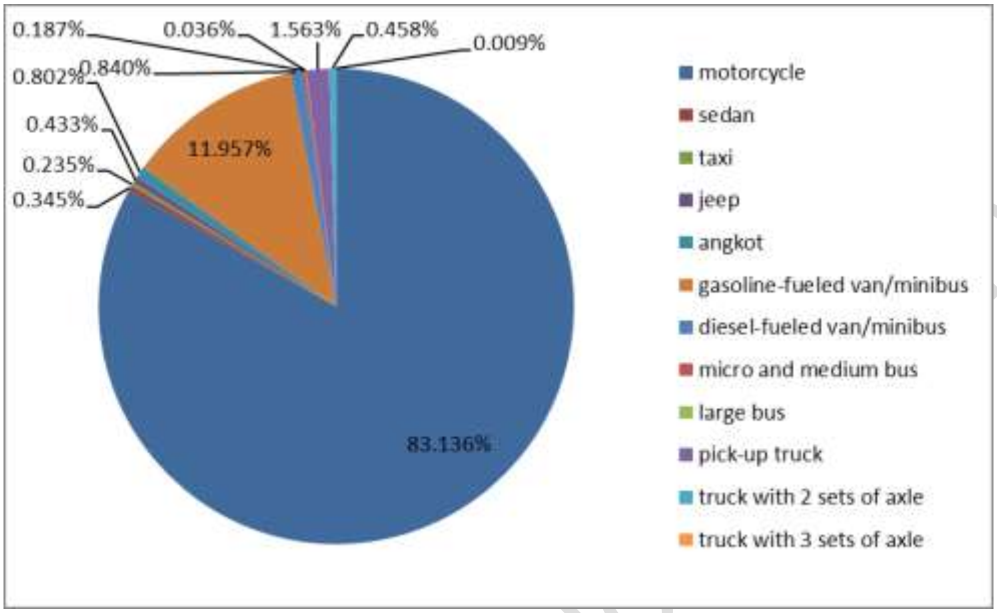

Figure 11. Vehicle composition on Jalan Stasiun Wonokromo

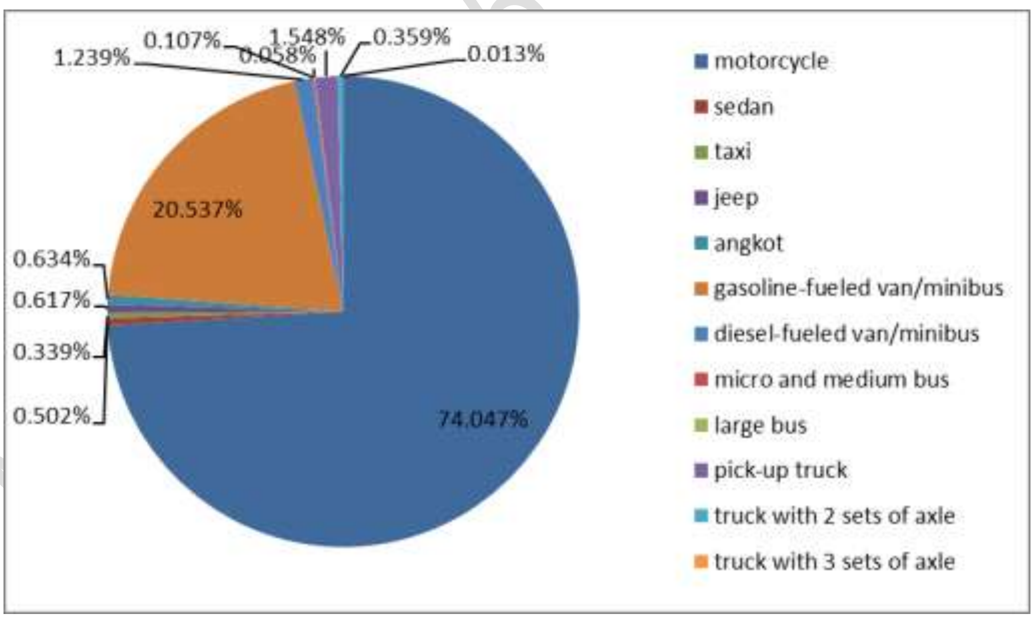

Figure 12. Vehicle composition on Jalan Bung Tomo

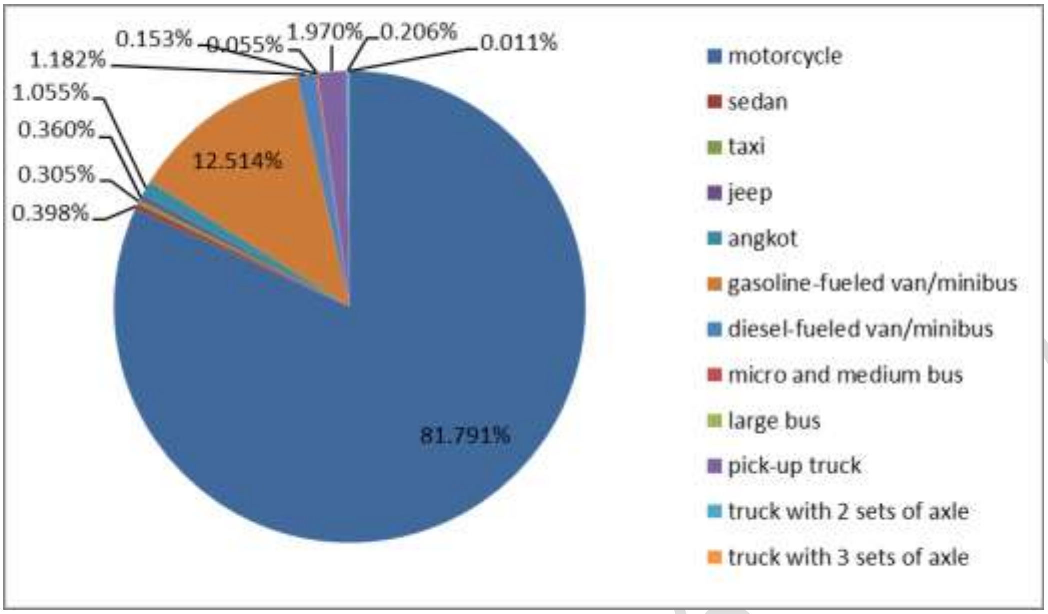

Figure 13. Vehicle composition on Jalan Raya Ngagel

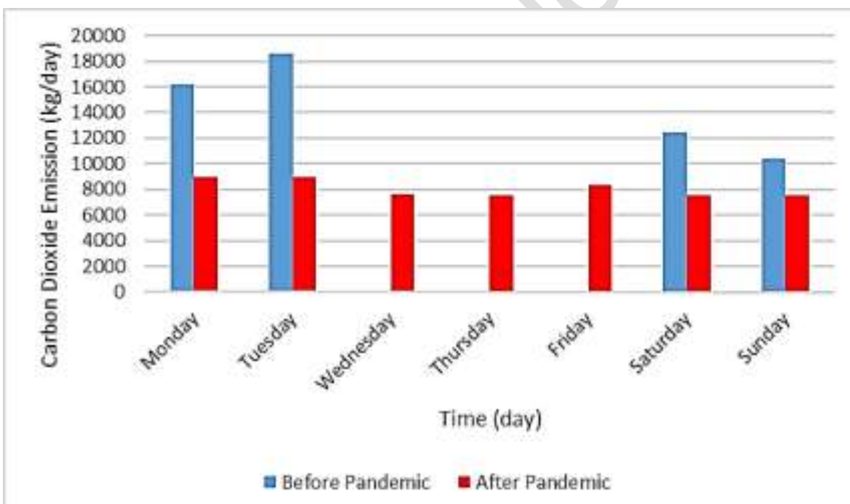

Figure 14. Estimated CO_2 emission on Jalan Stasiun Wonokromo before and after COVID-19

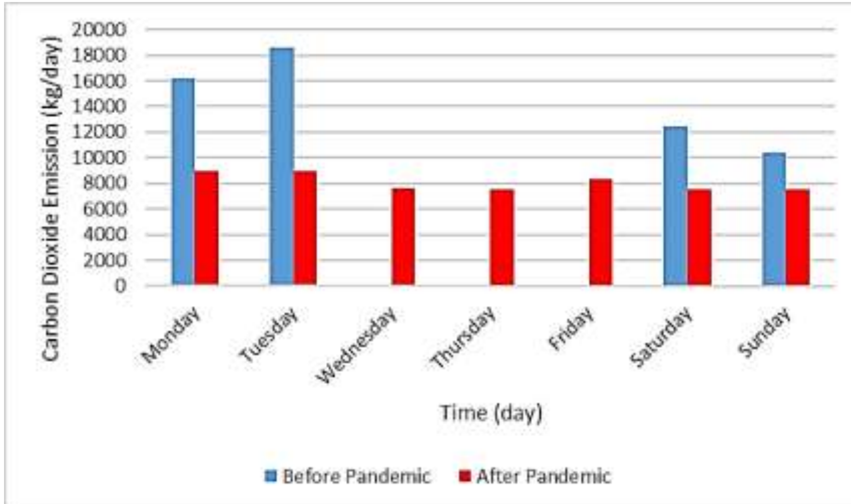

Figure 15. Estimated CO_2 emission on Jalan Bung Tomo before and after COVID-19

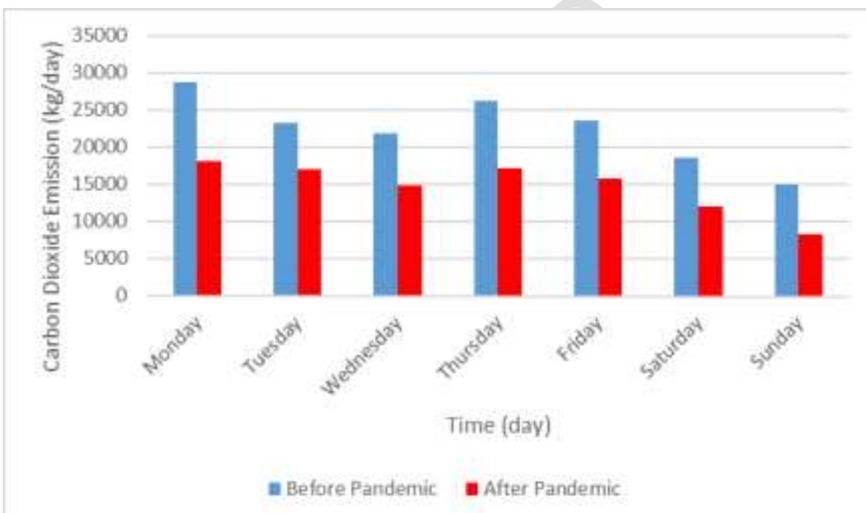

Figure 16. Estimated CO_2 emission on Jalan Raya Ngagel before and after COVID-19

Correlation between vehicle volume and type and estimated CO_2 emission

Estimated CO_2 emission based on vehicle type on Jalan Stasiun Wonokromo, Jalan Bung Tomo, and Jalan RayaNgagel is shown in Figures 17 - 19.

Figures 17 - 19 show gasoline-fueled van/minibus as the largest contributor to CO_2 emission. Gasoline-fueled van/minibus was the second largest number of vehicles after motorcycle, but it had a higher idle-fuel economy value and lower running-fuel economy value than motorcycle. This finding caused gasoline-fueled van/minibusto consume more fuel in engine operation [5, 7]. The lowest contributor to CO_2 emission was truck with threesets of axle. Truck with three sets of axle had a high fuel-economy value, although it was extremely smaller thanthe other vehicle types, thereby resulting in considerably lower CO_2 emission. The result of the Kolmogorov- Smirnov normality test shows that the data are not normally distributed because the number of vehicles has a sigvalue of 0.000 < (α) 5%. The Spearman correlation test shows that there is a correlation between the number ofvehicles and the CO2 emission load as can be seen from a significance value of 0.000 < (α) 5% and has a correlation coefficient of 0.979 for Jalan Station Wonokromo, 0.937 for Jalan Bung Tomo and 0.944 for Jalan Raya Ngagel. The correlation coefficient > 0.9 indicates a strong positive correlation, namely the higher the number of vehicles, the higher the CO2 emission load will be.

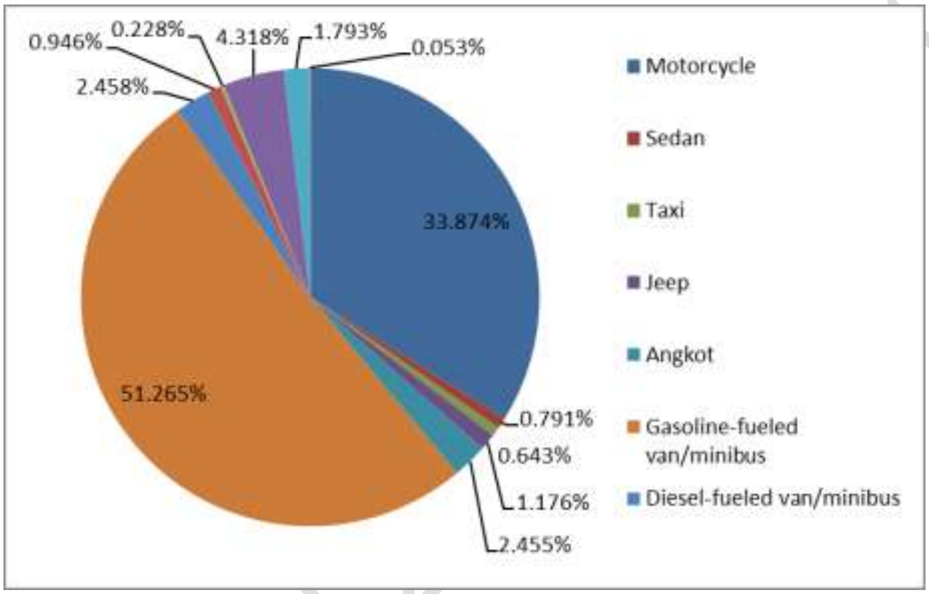

Figure 17. Estimated CO_2 emission based on vehicle type on Jalan Stasiun Wonokromo

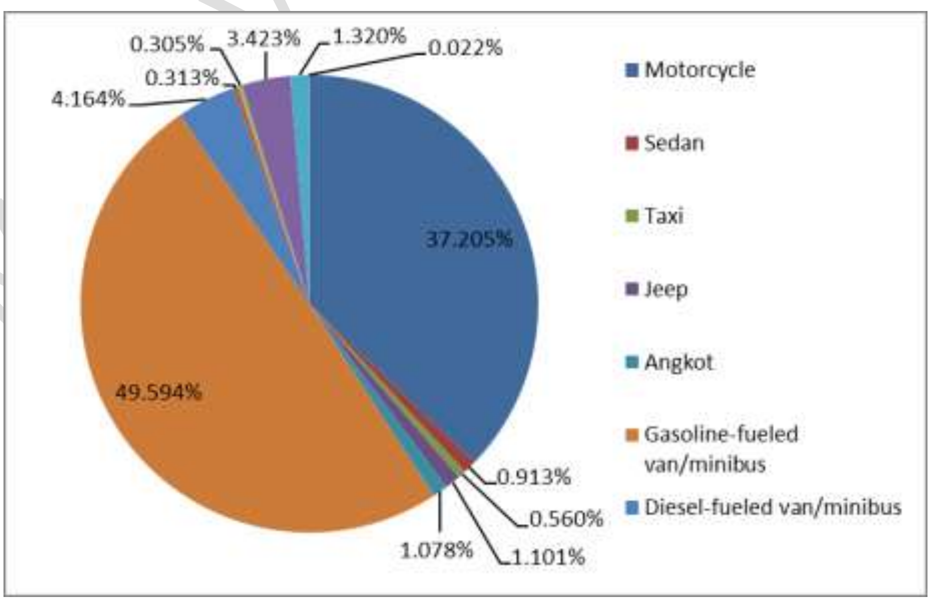

Figure 18. Estimated CO_2 emission based on vehicle type on Jalan Bung Tomo

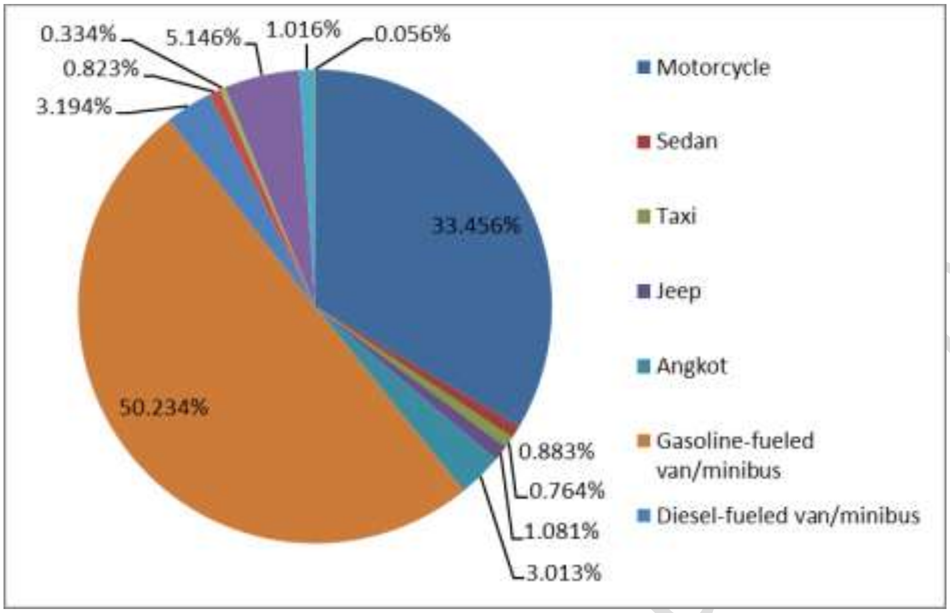

Figure 19. Estimated CO_2 emission based on vehicle type on Jalan Raya Ngagel

Conclusion

CO_2 emission on the primary arterial roads of Wonokromo District decreased owing to the COVID-19. It decreased by 55% on Jalan Stasiun Wonokromo, by 62% on Jalan Bung Tomo, and decreased by 37% on Jalan Raya Ngagel. The estimated CO_2 emission before COVID-19 was 5,259 kg/year on Jalan Wonokromo Station, 6,668 kg/year on Jalan Bung Tomo, and 8,202 kg/year on Jalan Raya Ngagel. The estimated CO_2 emission during COVID-19 was 2,945 kg/year on Jalan Stasiun Wonokromo, 2,478 kg/year on Jalan Bung Tomo, and 5,402 kg/year on Jalan Raya Ngagel. There is a correlation between the number of vehicles and estimated CO_2 emission load namely the higher the number of vehicles, the higher the CO_2 emission load will be.

Acknowledgement

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