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Estimation of CO_2 Emission Factors For Motorcycle and Passenger Car Use The International Vehicle Emissions Model in Banda Aceh

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Abstract
Private transportation is one of the main sources of emissions in Indonesia, which contributes to an increase in greenhouse gases due to excessive CO_2 emissions. This research aims to create a database of motorbike and passenger car activity, determine the CO_2 emission factor from various types of vehicles, and analyze the total CO_2 emissions from motorbikes and passenger cars in Banda Aceh. Data was collected through three survey methods: questionnaire, video, and GPS Logger. Questionnaires were distributed via Google Form to 400 respondents to determine patterns of use of motorbikes and passenger cars. Video surveys analyze traffic composition, while GPS Loggers are used to map driving conditions on Banda Aceh's arterial roads. The data obtained was then analyzed using descriptive statistics and the International Vehicle Emissions (IVE) model to calculate the emission factors for motorbikes and passenger cars in Banda Aceh City. The average Vehicle Specific Power (VSP) value for motorbikes was recorded at 1,449 kW/ton, while for passenger cars it was 1,456 kW/ton. The average CO_2 emission factor for motorbikes is 6.26 gr/km/hour per vehicle, and for passenger cars it reaches 51.54 gr/km/hour per vehicle. This CO_2 emission factor is relatively low in Banda Aceh. CO_2 emission predictions based on traffic volume show average motorbike emissions of 12.81 kg/km/hour, while passenger cars reach 72.83 kg/km/hour.
Keywords: *private transportation, vehicle emission factors, carbon dioxide, international vehicle emissions model, vehicle specific power*

Abstrak
Transportasi pribadi menjadi salah satu sumber utama emisi di Indonesia, yang menyumbang peningkatan gas rumah kaca akibat emisi CO_2 yang berlebihan. Penelitian ini bertujuan untuk membuat basis data aktivitas kendaraan sepeda motor dan mobil penumpang, menentukan faktor emisi CO_2 dari berbagai jenis kendaraan tersebut, serta menganalisis total emisi CO_2 dari sepeda motor dan mobil penumpang di Banda Aceh. Data dikumpulkan melalui tiga metode survei: kuesioner, video, dan GPS Logger. Kuesioner disebar melalui Google Form kepada 400 responden untuk mengetahui pola penggunaan sepeda motor dan mobil penumpang. Survei video menganalisis komposisi lalu lintas, sementara GPS Logger digunakan untuk memetakan kondisi berkendara di jalan arteri Banda Aceh. Data yang diperoleh kemudian dianalisis dengan statistik deskriptif dan model International Vehicle Emissions (IVE) guna menghitung faktor emisi kendaraan sepeda motor dan mobil penumpang di Kota Banda Aceh. Nilai rata-rata Vehicle Specific Power (VSP) sepeda motor tercatat sebesar 1,449 kW/ton, sementara untuk mobil penumpang sebesar 1,456 kW/ton. Faktor emisi CO_2 rata-rata untuk sepeda motor adalah 6,26 gr/km/jam per kendaraan, dan untuk mobil penumpang mencapai 51,54 gr/km/jam per kendaraan. Faktor emisi CO_2 ini tergolong rendah di Banda Aceh. Prediksi emisi CO_2 berdasarkan volume lalu lintas menunjukkan rata-rata emisi sepeda motor sebesar 12,81 kg/km/jam, sedangkan mobil penumpang mencapai 72,83 kg/km/jam.
Kata Kunci: *transportasi pribadi, faktor emisi kendaraan, karbon dioksida, model international vehicle emissions, vehicle specific power*

1. Introduction

Banda Aceh city as the capital of Aceh Province, experiences annual population growth. This condition has led to an increase in the use of private transportation modes. Transportation is essential and a key factor in enabling the community's smooth daily activities. Private vehicles, such as motorcycles and passenger cars, have become popular choices for residents due to their practicality and flexibility. According to BPS [1] the population of Banda Aceh has reached 270,321 people in 2020, most residents primarily use private transportation modes, such as motorcycles and passenger cars, as their main means of transport. Private transportation contributes to traffic congestion, and emissions from motorcycles and passenger cars in Banda Aceh have a negative impact in the form of air pollution. Motorcycles and passenger cars emit pollutants that can harm human health and the environment. Transportation activities significantly contribute to atmospheric air pollution. Each liter of burned fuel emits approximately 100 grams of CO, 30 grams of NOx, 2.5 kg of CO_2, and various other compounds, including sulfur compounds [2]. In an effort to reduce emissions, the European Union (EU) is adopting more environmentally friendly transportation technology. The Euro emission standard is a benchmark used by European countries to regulate air quality. The higher the Euro standard set, the lower the allowable limits for carbon dioxide, nitrogen oxide, carbon monoxide, and other particles that have a negative impact on human health and the environment. Indonesia is still using Euro 2 standards [3].

One of the substances emitted from motor vehicle exhaust is carbon dioxide (CO_2). Gases in the atmosphere that can trap sunlight are called greenhouse gases. If carbon dioxide (CO_2) is neglected, its concentration will accumulate in the atmosphere, potentially causing global warming, which in the long term can lead to climate change harmful to human life [4]. According to the World Health Organization [5], there are approximately 3.2 million deaths caused by air pollution each year. Different vehicle technologies can produce varying levels of emissions. The characteristics of private vehicles can be identified through various factors such as the brand of motorcycles and passenger cars, engine volume, model year, odometer readings, age, and emission standards of the motorcycles and passenger cars used by the residents of Banda Aceh[6]. Driving conditions, such as speed, acceleration, or deceleration, can affect the emission production of motorcycles and cars on arterial roads in Banda Aceh. The International Vehicle Emissions (IVE) model will be used to determine the emission factors of motorcycles and passenger cars in Banda Aceh.

This study uses the International Vehicle Emissions (IVE) model, which was developed in collaboration by the University of California, Riverside, the College of Engineering – Center for Environmental Research and Technology, Global Sustainable Systems Research, and the International Sustainable Systems Research Center. The model was first developed in 2008 and has been applied in over 10 cities in developing countries around the world, such as Mexico, India, Beijing, Shanghai, and China. The IVE model utilizes vehicle technology distribution, power-based drive factors, soak distribution (engine-off vehicle conditions), and meteorological factors specific to local conditions [7]. With its high resolution, direct user interface, and flexibility in multi-scale, multi-technology options, as well as base adjustment capabilities, the IVE model version 2.0.2 [8] was chosen to calculate the emission factors for motorcycles and passenger cars in Banda Aceh.

The objective of this research is to develop a database of motorcycle and passenger car activity in Banda Aceh City, to determine the CO_2 emission factors for various types of motorcycles and passenger cars based on local conditions in Banda Aceh City, and to analyze the amount of CO_2 emissions from motorcycles and passenger cars in Banda Aceh City.

2. Material and Methods

2.1 Research Location

The research is conducted through three surveys: a questionnaire, video recording, and GPS logging. The questionnaire will be distributed to motorcycle and passenger car users in Banda Aceh City. Video data will be recorded to analyze the traffic composition on the arterial roads Tgk. Moh. Daud Beureuh and Teuku Nyak Arief in Banda Aceh City. GPS loggers will be installed on selected motorcycles and passenger cars on these arterial roads, Tgk. Moh. Daud Beureuh and Teuku Nyak Arief, in Banda Aceh City.

2.2 Data Collection Techniques

Secondary data was obtained from relevant agencies, specifically the Revenue and Wealth Office of Banda Aceh City, through an official data request letter and other related sources. Primary data was collected through direct observation and by inventorying vehicle activities and travel patterns. According to Sugiyono [9] a questionnaire is a data collection technique conducted by giving a set of written questions or statements to respondents for them to answer. Questionnaires were distributed to respondents, specifically motorcycle and passenger car users aged 17 and above. The questionnaires, in the form of Google Forms, were distributed online. The purpose of the questionnaire was to create a database of vehicle technology characteristics; respondents also answered questions such as how many times they start their engines per day and how many hours they keep their engines on or off. Respondents were asked to provide information including vehicle make, engine volume, odometer reading, age, and emission standards of their motorcycles or passenger cars if they chose these as their mode of transportation. Additionally, other personal data was collected to understand respondents' demographic profiles, including gender, age, education level, occupation, mode choice, and monthly income.

The GPS Logger device was used to analyze driving conditions on the arterial roads Tgk. Moh. Daud Beureuh and Teuku Nyak Arief in Banda Aceh City. Driving conditions such as speed, acceleration, and deceleration can affect the emission levels produced by motorcycles and cars on these arterial roads in Banda Aceh City.

2.3 Data Processing

Questionnaire Data Processing

The data processing stage is carried out after the questionnaire distribution is complete. The questionnaire data processing includes:

a. Distribution of Private Mode Usage
b. Distribution of Respondent Characteristics (socio-economic)
c. Distribution of Motorcycle Characteristics

The questionnaire data processing is done through tabulation using Microsoft Excel to facilitate data analysis.

Video Recording Data Processing

Three digital video cameras are positioned at the roadside or above the road to record vehicles passing on the arterial roads Tgk. Moh. Daud Beureuh and Teuku Nyak Arief in Banda Aceh City. This data is then reviewed manually to determine traffic volume. It is important to set the cameras at an appropriate height to clearly capture traffic on one side of the arterial road. Useful data can be captured with cameras placed along the roadside.

2.4 Data Analysis

Vehicle Specific Power (VSP)

This data is collected by traveling along each segment of the arterial roads Tgk. Moh. Daud Beureuh and Teuku Nyak Arief in Banda Aceh City using a GPS Logger to record the travel time required for vehicles passing through these segments. The recorded travel time includes any delays encountered during peak hours in the morning, noon, and evening. Data collection is conducted using one motorcycle and one passenger car, both driven by the researcher, with the vehicles provided by the researcher. The GPS (Global Positioning Satellite) Logger is attached to the selected motorcycle and passenger car for data collection. Additionally, the GPS Logger is configured to record data at one-second intervals, meaning speed is captured every second. The GPS tracker has an accuracy of 0.1 m/s for speed and 1-5 meters for horizontal positioning, though accuracy is lower for altitude measurements [10].

This data collection process uses a GPS Logger to identify changes in vehicle speed every second as the vehicle travels along the arterial roads of Tgk. Moh. Daud Beureuh and Teuku Nyak Arief in Banda Aceh City. In the data analysis, these speed changes are used to map the vehicle's travel path. The collected data is then processed to calculate the Vehicle Specific Power (VSP) value and the vehicle bin value at each test segment using Equation 1. According to [11] VSP is defined as the force per unit mass to overcome road slope (grade), rolling resistance and aerodynamic drag, as well as inertia acceleration. The obtained bin values are then analyzed using the International Vehicle Emission (IVE) model application.

$$VSP = v*\{1.1 * \alpha + 9.81*[\arctan (\sin (grade))\} + 0.132\} + 0.000302 * v^3 \quad (1)$$

$$grade = (h\_(t=0\ ) - h\_(t=-1))/d((t=-1 \text{ to } 0)) \quad (2)$$

VSP is a vehicle specific power (kW/ton), v represents vehicle speed (km/h), grade is slope of the road, α is a vehicle acceleration (m/s^2), a 9.81 is coefficient of gravity (m/s^2), a 0.132 is rolling resistance coefficient and 0.000302 is a tensile coefficient.

Vehicle Kilometer Travelled (VKT)

Motorcycles and passenger cars are types of passenger transport that do not have fixed routes, so the Vehicle Kilometer Travelled (VKT) value depends on the activities and destinations of the drivers. In this study, the VKT calculation for motorcycles and passenger cars was obtained through an odometer survey installed on each vehicle. Vehicle Kilometer Travelled (VKT) refers to the distance traveled by the vehicle, multiplied by the emission factor that will be measured. Data entry and processing in the International Vehicle Emission (IVE) model application are used to determine the emission characteristics of vehicles based on the vehicle characteristics and the results of the Vehicle Specific Power (VSP) calculation for motorcycles and passenger cars on the test location segment. The data entry and processing in the IVE model application involve four main sections: Base Adjustment, Fleet, Location, and Calculation.

3. Results and Discussion

3.1 Private Vehicle Characteristics

Data from the questionnaire on motorcycle and passenger car characteristics are shown in **Figure 1.** which presents the characteristics of motorcycles in Banda Aceh, and **Figure 2**. which illustrates the characteristics of passenger cars in Banda Aceh.

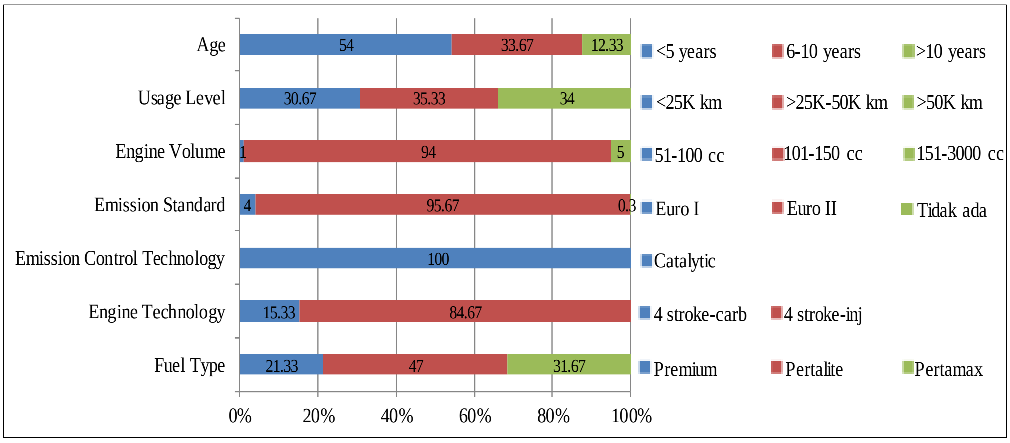

Figure 1. Characteristics of Motorcycles in Banda Aceh

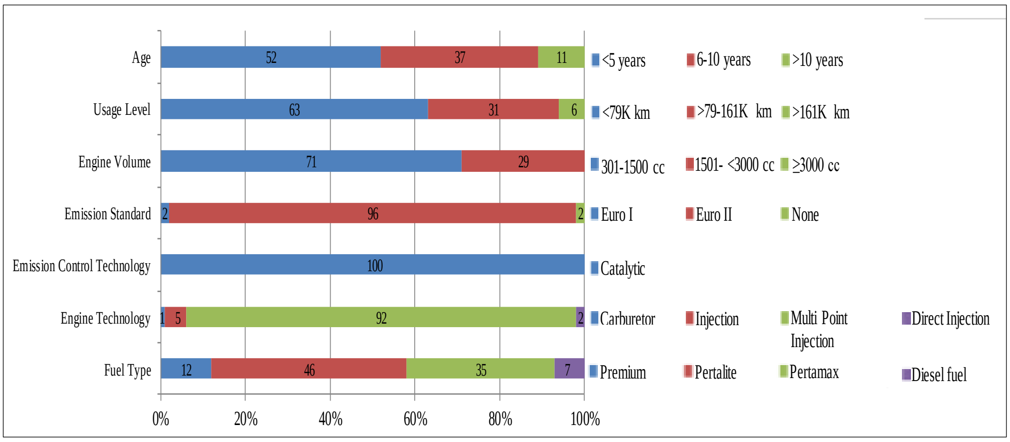

Figure 2. Characteristics of Passenger Cars in Banda Aceh

3.2 Driving Conditions

The driving conditions for motorcycles and passenger cars were obtained from a survey using a GPS Logger conducted over 6 days. From Table 1 and Table 2, it can be seen that the highest speed of motorcycles, as recorded by the GPS Logger on the arterial roads of Tgk. Moh. Daud Beureuh and Teuku Nyak Arief streets in Banda Aceh, on Wednesday morning, had an average speed of 29.878 km/h. Meanwhile, the highest speed of passenger cars, as recorded by the GPS Logger on the same arterial roads in Banda Aceh on Wednesday morning, had an average speed of 33.359 km/h.

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Table 1. Driving Conditions for Motorcycles

Driving Conditions for Motorcycles		
Time		**Average Speed (km/h)**
Monday	Morning (07:00 – 08:00 WIB)	27.857
	Afternoon (12:00 – 13:00 WIB)	27.265
	Evening (16:00 – 17:00 WIB)	26.352
Wednesday	Morning (07:00 – 08:00 WIB)	29.878
	Afternoon (12:00 – 13:00 WIB)	27.140
	Evening (16:00 – 17:00 WIB)	23.403
Thursday	Morning (07:00 – 08:00 WIB)	29.223
	Afternoon (12:00 – 13:00 WIB)	27.515
	Evening (16:00 – 17:00 WIB)	26.776

Table 2. Driving Conditions for Passenger Cars

Driving Conditions for Passenger Cars		
Time		**Average Speed (km/h)**
Monday	Morning (07:00 – 08:00 WIB)	28.533
	Afternoon (12:00 – 13:00 WIB)	28.611
	Evening (16:00 – 17:00 WIB)	28.259
Wednesday	Morning (07:00 – 08:00 WIB)	33.359
	Afternoon (12:00 – 13:00 WIB)	28.107
	Evening (16:00 – 17:00 WIB)	25.808
Thursday	Morning (07:00 – 08:00 WIB)	30.820
	Afternoon (12:00 – 13:00 WIB)	27.380
	Evening (16:00 – 17:00 WIB)	25705

3.3 Vehicle Specific Power (VSP)

Tables 3 and **4** present the Vehicle Specific Power (VSP) values for motorcycles and passenger cars during peak morning, afternoon, and evening hours. The average VSP value for motorcycles is 1.449 kW/ton, with an average engine load value of 1.385 and a bin value of 12. The average VSP value for passenger cars is 1.456 kW/ton, with an average engine load value of 1.401 and a bin value of 12

Tabel 3. Vehicle Specific Power (VSP) for Motorcycles

Vehicle Specific Power (VSP) for Passenger Cars					
Waktu		**Average Speed (km/h)**	**Average VSP Value (kW/ton)**	**Average Engine Power Value**	**Average VSP BIN Value**
Monday	Morning (07:00 – 08:00 WIB)	28.533	1.432	1.450	12
	Afternoon (12:00 – 13:00 WIB)	28.611	1.440	1.444	12
	Evening (16:00 – 17:00 WIB)	28.259	1.421	1.381	12
Wednesday	Morning (07:00 – 08:00 WIB)	33.359	1.857	1.413	12
	Afternoon (12:00 – 13:00 WIB)	28.107	1.409	1.407	12
	Evening (16:00 – 17:00 WIB)	25.808	1.293	1.377	11
Thursday	Morning (07:00 – 08:00 WIB)	30.820	1.577	1.447	12
	Afternoon (12:00 – 13:00 WIB)	27.380	1.370	1.357	11
	Evening (16:00 – 17:00 WIB)	25.705	1.306	1.335	11
Average		**28.059**	**1.456**	**1.401**	**12**

Table 4. Vehicle Specific Power (VSP) for Passenger Cars

Vehicle Specific Power (VSP) for Motorcycles						
Time		**Average Speed (km/h)**	**Average VSP Value (kW/ton)**	**Average Engine Power Value**	**Average VSP BIN Value**
Monday	Morning (07:00 – 08:00 WIB)	27.857	1.460	1.393	12
	Afternoon (12:00 – 13:00 WIB)	27.265	1.386	1.439	12
	Evening (16:00 – 17:00 WIB)	26.352	1.318	1.419	11
Wednesday	Morning (07:00 – 08:00 WIB)	29.878	1.590	1.376	12
	Afternoon (12:00 – 13:00 WIB)	27.140	1.572	1.318	12
	Evening (16:00 – 17:00 WIB)	23.403	1.162	1.384	11
Thursday	Morning (07:00 – 08:00 WIB)	29.223	1.608	1.367	12
	Afternoon (12:00 – 13:00 WIB)	27.515	1.475	1.355	12
	Evening (16:00 – 17:00 WIB)	26.776	1.467	1.414	12
Average		**27.268**	**1.449**	**1.385**	**12**

3.4 Fleet Input for Motorcycles and Passenger Cars with the IVE Model

Each vehicle technology is associated with an Index Number. Each index number corresponds to a description of the vehicle technology used in the IVE model. The Fleet file contains a list of the travel fractions of vehicles according to each technology. The IVE model includes 1,372 pre-defined technologies and an additional 45 undefined technologies. These technologies form the fleet of vehicles operating in the city of Banda Aceh.

The technologies that make up the fleet of motorcycles and passenger cars operating in the city of Banda Aceh are grouped using parameters that can be found in **Table 5** and **Table 6**.

Table 5. Technology Parameters that Form the Motorcycle Fleet in Banda Aceh City

No	Description	Fuel Type	Vehicle Engine Capacity Size	Weight	Fuel Control	Vehicle Fuel Supply System	Vehicle Emission Control Technology	Vehicle Trip Length	Frequency	Frekuensi	Percentage
1	Small Engine	Petrol	51 - 100 cc	Little	4 Stroke	Carburetor	Catalytic	>50,000 km	1235	3	1.00
2	Small Engine	Petrol	100 - 300 cc	Medium	4 Stroke	Carburetor	Catalytic	>25,000 km - 50,000 km	1237	6	2.00
3	Small Engine	Petrol	100 - 300 cc	Medium	4 Stroke	Carburetor	Catalytic	>50,000 km	1238	37	12.33
4	Small Engine	Petrol	100 - 300 cc	Medium	4 Stroke	Injection	Catalytic	<25,000 km	1245	92	30.67
5	Small Engine	Petrol	100 - 300 cc	Medium	4 Stroke	Injection	Catalytic	>25,000 km - 50,000 km	1246	100	33.33
6	Small Engine	Petrol	100 - 300 cc	Medium	4 Stroke	Injection	Catalytic	>50,000 km	1247	62	20.67
Total Motorcycles										**300**	**100.00**

Table 6. Technology Parameters that Form the Passenger Car Fleet in Banda Aceh City

No	Description	Fuel Type	Engine Capacity Size	*Vehicle Weight*	Fuel Supply System	Vehicle Emission Standard	Trip Length	Index	Frequency	Percentage
1	Auto/Small Truck	Petrol	301 - 1500 cc	Light	Carburetor 3 Stroke	-	>161,000 km	29	1	1.00
2	Auto/Small Truck	Petrol	301 - 1500 cc	Light	Multi Point Injection	Euro II	<79,000 km	180	44	44.00
3	Auto/Small Truck	Petrol	301 - 1500 cc	Light	Multi Point Injection	Euro II	79,000 km - 161,000 km	181	23	23.00
4	Auto/Small Truck	Petrol	301 - 1500 cc	Light	Multi Point Injection	Euro II	>161,000 km	182	2	2.00
5	Auto/Small Truck	Petrol	1501 - <3000 cc	Medium	Multi Point Injection	Euro II	<79.000 km	183	17	17.00
6	Auto/Small Truck	Petrol	1501 - <3000 cc	Medium	Multi Point Injection	Euro II	79,000 km - 161,000 km	184	6	6.00
10	Auto/Small Truck	Diesel	301 - 1500 cc	Light	Direct Injection	-	>161,000 km	758	1	1.00
11	Auto/Small Truck	Diesel	1501 - <3000 cc	Medium	Direct Injection	Euro I	>161,000 km	761	1	1.00
9	Auto/Small Truck	Diesel	1501 - <3000 cc	Medium	Fuel Injection	Euro I	>161,000 km	788	1	1.00

3.5 CO_2 Emission Calculation Results Using the IVE Model

The calculated result is the mass emission for the distance or time displayed. In this study, the chosen mass unit is grams, and the distance unit specified in the location file is kilometers. The result calculated is the grams of CO_2 emissions per kilometer traveled. The daily result will sum all the hourly CO_2 emission information found in the location file simultaneously. The location file contains information on hourly CO_2 emissions during peak hours in the morning, afternoon, and evening.

The CO_2 running result refers to the amount of CO_2 flowing on the arterial road for a single trip (from origin to destination and back), using equation 3. The CO_2 start result refers to the CO_2 produced during a single warm-up instance when starting the vehicle, using equation 4. The VSP bin input is based on 3 days of surveys during each peak hour for motorcycles and passenger cars.

$$Q_{running} = \Sigma_t\{f_{[t]}*\Sigma_d\,[Q_{[t]} * \bar{U}_{FTP}*f_{[dt]} *K_{[dt]}]\}/\bar{U}_C \quad (3)$$

$$Q_{start} = \Sigma_t\{f_{[t]}*Q_{[t]}*\Sigma d[f_{[dt]}*K_{[dt]}]\} \quad (4)$$

Table 7. CO_2 Emission Estimation Results for Motorcycles

Time		CO_2 Start Emission (gr/km/hour)	CO_2 Running Emission (gr/km/hour)	Total CO_2 Emission (gr/km/hour)
		(1)	**(2)**	**(1+2)**
Monday	Morning (07:00 – 08:00 WIB)	24.14	5,064.5	5,088.64
	Afternoon (12:00 – 13:00 WIB)	24.14	5,081.05	5,105.19
	Evening (16:00 – 17:00 WIB)	24.14	5,054.1	5,078.24
	Average CO_2 Emission	**24.14**	**5,066.55**	**5,090.69**
Wednesday	Morning (07:00 – 08:00 WIB)	24.14	5,611.21	5,635.35
	Afternoon (12:00 – 13:00 WIB)	24.14	5,149.45	5,173.59
	Evening (16:00 – 17:00 WIB)	24.14	4,996.54	5,020.68
	Average CO_2 Emission	**24.14**	**5,252.40**	**5,276.54**
Thursday	Morning (07:00 – 08:00 WIB)	24.14	5,318.92	5,343.06
	Afternoon (12:00 – 13:00 WIB)	24.14	4,939.13	4,963.27
	Evening (16:00 – 17:00 WIB)	24.14	4,947.45	4,971.59
	Average CO_2 Emission	**24.14**	**5,068.5**	**5,092.64**
Average CO_2 Emission			**5,129.15**	**5,153.29**

Table 8. CO_2 Emission Estimation Results for Passenger Cars

Time		CO_2 Start Emission (gr/km/hour)	CO_2 Running Emission (gr/km/hour)	Total CO_2 Emission (gr/km/hour)
		(1)	**(2)**	**(1+2)**
Monday	Morning (07:00 – 08:00 WIB)	11.95	1,857.23	1,869.18
	Afternoon (12:00 – 13:00 WIB)	11.95	1,893.15	1,905.09
	Evening (16:00 – 17:00 WIB)	11.95	1,845.23	1,857.18
	Average CO_2 Emission	**11.95**	**1,865.20**	**1,877.15**
Wednesday	Morning (07:00 – 08:00 WIB)	11.95	1,917.21	1,929.16
	Afternoon (12:00 – 13:00 WIB)	11.95	1,990.82	2,002.77
	Evening (16:00 – 17:00 WIB)	11.95	1,796.29	1,808.24
	Average CO_2 Emission	**11.95**	**1,901.44**	**1,913.39**
Thursday	Morning (07:00 – 08:00 WIB)	11.95	1,932.98	1,944.93
	Afternoon (12:00 – 13:00 WIB)	11.95	1,870.37	1,882.32
	Evening (16:00 – 17:00 WIB)	11.95	1,910.66	1,922.61
	Average CO_2 Emission	**11.95**	**1,904.67**	**1,916.62**
Average CO_2 Emission		**11.95**	**1,890.44**	**1,902.39**

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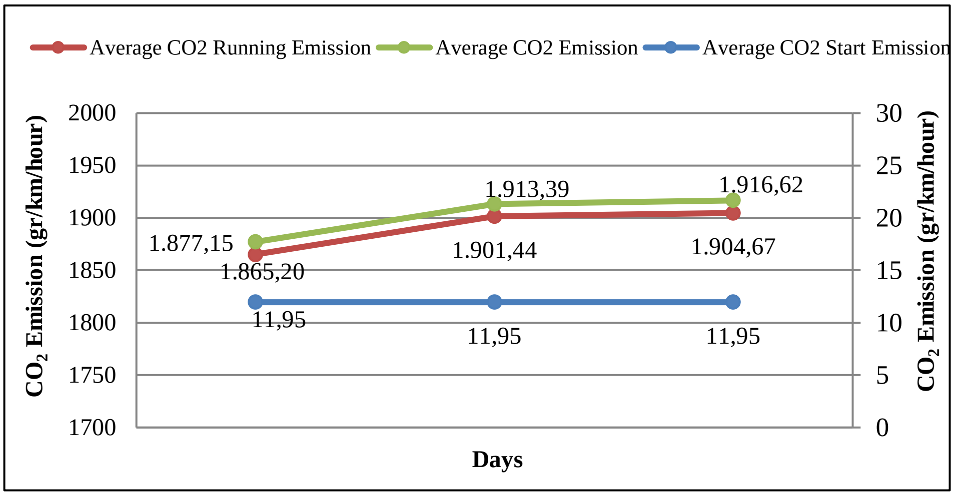

Figure 3. CO_2 Emission Estimation Results for Motorcycles

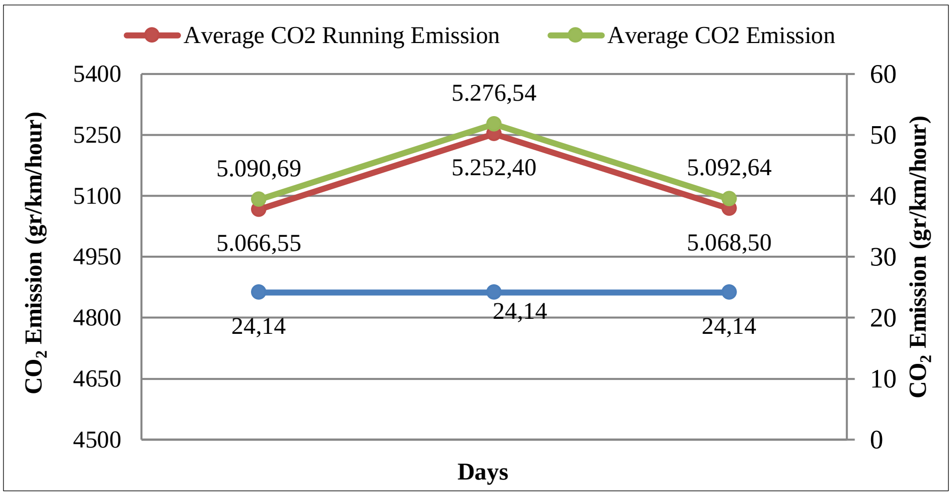

Figure 4. CO_2 Emission Estimation Results for Passenger Cars

Based on **Table 7** and **Figure 3**, the CO_2 emission estimation for motorcycles using the IVE Model is shown. It is concluded that 300 motorcycle users will generate an average CO_2 emission of 11.95 grams of CO_2 for one start and 1,890.44 grams for one kilometer of running per hour. Based on **Table 8** and **Figure 4**, the CO_2 emission estimation for passenger cars is shown. It is concluded that 100 passenger car users will generate an average CO_2 emission of 24.14 grams of CO_2 for one start and 5,129.15 grams for one kilometer of running per hour.

3.6 Emission Factor

The calculation of the CO_2 emission factor in Ho Chi Minh City, Vietnam [12] using the IVE Model is used as a comparison for the CO_2 emission factor calculation in Banda Aceh. According to the study (DUNG, 2015), the average emission factor for motorcycles is 60.13 gr/km per vehicle, while passenger cars will generate an average emission factor of 132.90 gr/km per vehicle.

Table 9. CO_2 Emission Factor for Motorcycles and Passenger Cars in Banda Aceh City Generated from the IVE Model

CO_2 Emission Factor			
	Time	**Motorcycle (gr/km/hour)**	**Passenger Car (gr/km/hour)**
Monday	Morning (07:00 – 08:00 WIB)	6.23	50.89
	Afternoon (12:00 – 13:00 WIB)	6.35	51.05
	Evening (16:00 – 17:00 WIB)	6.19	50.78
	Average CO_2 Emission Factor	**6.26**	**50.91**

Wednesday	Morning (07:00 – 08:00 WIB)	6.43	56.35
	Afternoon (12:00 – 13:00 WIB)	6.68	51.74
	Evening (16:00 – 17:00 WIB)	6.03	50.21
	Average CO_2 Emission Factor	**6.38**	**52.77**
Thursday	Morning (07:00 – 08:00 WIB)	6.48	53.43
	Afternoon (12:00 – 13:00 WIB)	6.27	49.63
	Evening (16:00 – 17:00 WIB)	6.41	49.72
	Average CO_2 Emission Factor	**6.39**	**50.93**
Average CO_2 Emission Factor		**6.26**	**51.54**

Based on **Table 9**, it shows the CO_2 emission factor per motorcycle and per passenger car from three days of observation. It is concluded that motorcycles generate an average CO_2 emission factor of 6.26 gr/km/hour per vehicle. Meanwhile, the average CO_2 emission factor for passenger cars is 51.54 gr/km/hour per vehicle. The emission factors obtained will serve as a reference for calculating the predicted CO_2 emissions of motorcycles and passenger cars based on traffic volume in Banda Aceh City.

In the CO_2 emission factor study in Ho Chi Minh City, Vietnam [12], the questionnaire was distributed using 1,874 samples, with 1,707 motorcycle users and 167 passenger car users. The most dominant engine technology for motorcycles in Ho Chi Minh City is the 4-stroke carburetor engine, with a percentage of 57.41%. Meanwhile, passenger cars with a carburetor system in Ho Chi Minh City account for 23.95%.

3.7 Traffic Volume

Traffic volume represents the combination and number of vehicles in the traffic flow. The movement of traffic passing through the intersection arm during each green light phase consists of straight movements, right turns, and left turns, categorized into three types: Light Vehicle (LV), Motorcycle (MC), and Heavy Vehicle (HV).Three digital video cameras were installed along the roadside at three survey points, namely the road section of Tgk. Moh. Daud Beureuh in front of BTPN, Simpang Jambo Tape, and Simpang Oman in Banda Aceh, to capture images of vehicles passing through the arterial roads of Tgk. Moh. Daud Beureuh and Teuku Nyak Arief streets in Banda Aceh. The location of the first video survey point is in front of BTPN KC Banda Aceh, on the two-way road section of Tgk. Moh. Daud Beureuh, which leads east towards the Jambo Tape intersection and west towards the Simpang Lima intersection.

The second video survey point is at the Jambo Tape intersection: the eastern approach is Jalan T. Nyak Arief, which provides access to the educational center in Darussalam, including the Syiah Kuala University campus, while the western approach is Jalan Daud Beureueh, which leads to the center of Banda Aceh. The third video survey point is at the Oman intersection: the eastern approach is Jalan T. Nyak Arief, which leads to the educational center in Darussalam, including the Syiah Kuala University campus, and the western approach is Jalan Daud Beureueh.

Based on the field observations, the peak busy hours were selected. The results obtained are as follows:

Table 10. Average Traffic Volume During Peak Hours in Both Directions on Monday

Survey Time(WIB)	MC (vehicles/hour)	LV (vehicles/hour)	Total (vehicles/hour)
07:00-08:00	2,277	1,550	3,827
12:00-13:00	1,895	1,270	3,165
16.00-17.00	1,745	1,256	3,001

Table 11. Average Traffic Volume During Peak Hours in Both Directions on Wednesday

Survey Time(WIB)	MC (vehicles/hour)	LV (vehicles/hour)	Total (vehicles/hour)
07:00-08:00	2,185	1,459	3,644
12:00-13:00	1,992	1,595	3,587
16.00-17.00	1,982	1,263	3,245

Table 12. Average Traffic Volume During Peak Hours in Both Directions on Thursday

Survey Time(WIB)	MC (kend/jam)	LV (kend/jam)	Total (kend/jam)
07:00-08:00	2.275	1,527	3,801
12:00-13:00	1,890	1,468	3,358
16.00-17.00	1,923	1,315	3,238

3.8 Prediction of CO_2 Emissions for Motorcycles and Passenger Cars Based on Traffic Volume

In the calculation of CO_2 emissions in Banda Aceh, the required data includes the average vehicle volume per hour (vehicles/hour) and the emission factor (grams/km/hour per vehicle).

Tabel 13. Predicted CO_2 Emissions for Motorcycles and Passenger Cars Based on Traffic Volume

Time		Motorcycle (kg/km/hour)	Passenger Car (kg/km/hour)
Monday	Morning (07:00 – 08:00 WIB)	14.19	78.89
	Afternoon (12:00 – 13:00 WIB)	12.04	64.84
	Evening (16:00 – 17:00 WIB)	10.80	63.78
	Average CO_2 Emissions	**12.34**	**69.17**
Wednesday	Morning (07:00 – 08:00 WIB)	14.05	82.24
	Afternoon (12:00 – 13:00 WIB)	13.30	82.50
	Evening (16:00 – 17:00 WIB)	11.95	63.39
	Average CO_2 Emissions	**13.10**	**76.04**
Thursday	Morning (07:00 – 08:00 WIB)	14.75	81.57
	Afternoon (12:00 – 13:00 WIB)	11.86	72.88
	Evening (16:00 – 17:00 WIB)	12.32	65.38
	Average CO_2 Emissions	**12.98**	**73.27**
Average CO_2 Emissions		**12.81**	**72.83**

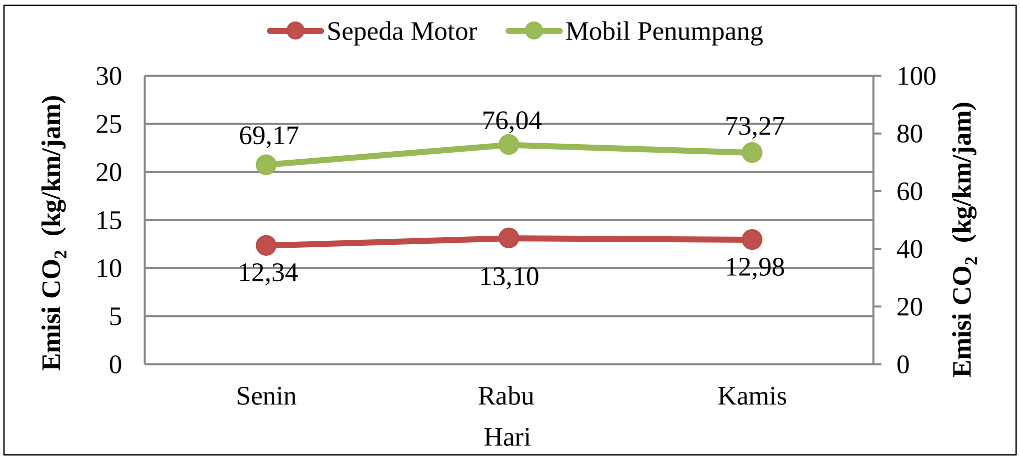

Figure 5. Predicted CO_2 Emissions for Motorcycles and Passenger Cars Based on Traffic Volume

Based on **Figure 5**, the predicted CO_2 emissions for motorcycles based on traffic volume result in an average CO_2 emission of 12.81 kg/km/hour. Meanwhile, the predicted CO_2 emissions for passenger cars based on traffic volume result in an average CO_2 emission of 72.83 kg/km/hour.

From these CO_2 emission values, it can be observed that the emission levels vary each day. This is due to the concentration of CO_2 in the air at different times of the day, which is influenced by the traffic activity of motorcycles and passenger cars in Banda Aceh that pass through the road segments. The higher the number of vehicles passing by, the higher the CO_2 emission levels in the air along those roads.

4. Conclusion

According to the data obtained from the GPS Logger survey to assess the driving conditions of vehicles on the arterial roads of Tgk. Moh. Daud Beureuh and Teuku Nyak Arief in Banda Aceh, the highest speed of motorcycles on Wednesday morning had an average speed of 29.878 km/h. Meanwhile, the highest speed of passenger cars on Wednesday morning had an average speed of 33.359 km/h. The average Vehicle Specific Power (VSP) value for motorcycles is 1.449 kW/ton with an average engine pressure value of 1.385 and bin value 12. Meanwhile, for passenger cars, the average VSP value is 1.456 kW/ton with an average engine pressure value of 1.401 and bin value 12. The CO_2 emission factor per motorcycle and per passenger car from the three days of observation shows that motorcycles produce an average CO_2 emission factor of 6.26 gr/km/hour per vehicle, while passenger cars produce an average CO_2 emission factor of 51.54 gr/km/hour per vehicle. The predicted CO_2 emissions for motorcycles based on traffic volume result in an average CO_2 emission of 12.81 kg/km/hour. The predicted CO_2 emissions for passenger cars based on traffic volume result in an average CO_2 emission of 72.83 kg/km/hour.

It is important to be meticulous in determining the classification of private vehicle types and the identification of driving conditions in order to reduce potential human errors. Efforts to reduce CO_2 emissions can be made by engaging the public through socialization programs to encourage regular inspection, maintenance, and emission testing of their vehicles, ensuring that their engines do not produce high emissions. Reducing the use of private vehicles can be achieved by improving the availability of mass public transportation that uses environmentally friendly fuels.

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