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Potential air pollutant emission from private vehicles based on vehicle route

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Abstract. Air emissions related to the transportation sector has been identified as the second largest emitter of ambient air quality in Indonesia. This is due to large numbers of private vehicles commuting within the city as well as inter-city. A questionnaire survey was conducted in Semarang city involving 711 private vehicles consisting of cars and motorcycles. The survey was conducted in random parking lots across the Semarang districts and in vehicle workshops. Based on the parking lot survey, the average distance private cars travelled in kilometers (VKT) was 17,737 km/year. The machine start-up number of cars during weekdays; weekends were on average 5.19 and 3.79 respectively. For motorcycles the average of kilometers travelled was 27,092 km/year. The machine start-up number of motorcycles during weekdays and weekends were on average 5.84 and 3.98, respectively. The vehicle workshop survey showed the average kilometers travelled to be 9,510 km/year for motorcycles, while for private cars the average kilometers travelled was 21,347 km/year. Odometer readings for private cars showed a maximum of 3,046,509 km and a minimum of 700 km. Meanwhile, for motorcycles, odometer readings showed a maximum of 973,164 km and a minimum of roughly 54.24 km. Air pollutant emissions on East-West routes were generally higher than those on South-North routes. Motorcycles contribute significantly to urban air pollution, more so than cars. In this study, traffic congestion and traffic volume contributed much more to air pollution than the impact of fluctuating terrain.

1. Intorduction

Conventional air pollutants and significant levels of greenhouse gases (GHGs) in the atmosphere originate from the transportation sector via vehicle emissions [1]. The major GHGs are carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O). Existing research shows that a large percentage of urban transport emissions contributions are extremely high.

Factors that affect the magnitude of air pollutants include (but are not limited to) engine combustion technology, the sort-quality of consumed fuel, exhaust device control, type of road surface-terrain and vehicle operation (driver behavior). Appropriate measures for abating air emissions related to the transportation sector have been adopted in Indonesia. Several measures have already been implemented in recent years for managing the transport sector and have co-benefited pollution reduction. These policies include the application of an intelligent transportation system (ITS), implementing traffic impact control, introducing a bus rapid transport (BRT) system, developing non-motorized transport, renewing paratransit public transportation and introducing smart driving training. All of these measures are implemented initially in big cities and claimed for conventional air pollutants mitigation as well as a reduction in GHGs. However, such policies lack supporting data for calculating hypothetical reduction. For example, ITS applications include vehicle speed before and after deploying ITS devices, actual shifting of private vehicles to pedestrian in NMT program, actual shifting mode of private vehicles to BRT system in BRT system program. Many studies have attempted to reveal this data in a bid to better calculate potential emissions reduction. The Ministry of Transportation must sort all data to complete a review of emission reduction efforts.

To date, assessing air quality in a specific area requires a vehicle population estimation [2]. In this case, identifying recent and detailed fleet being investigated is important. A source inventory must be robust and detailed, including statistical data featuring various vehicle categories and their specific operating conditions [3]. The vehicle routes are important for determining real emission according to the vehicles involved. Generally, the more flat a terrain, the higher speed it will produce; however this may not be true if we also consider traffic volume. Thus, in this study, we aim to discover the different air pollutant emissions due to cars/motorcycles travelling different routes.

2. Literature Review

Conventional air pollutants such as nitrogen oxides, sulfur dioxide and carbon monoxide, as well as hydrocarbons, are emitted from internal combustion engine in vehicles. The dominant emission from the transport sector is nitrogen oxide, while for diesel engines, SO2 emission is also a concern, due to the sulfur content in diesel fuel. Emission from the transport sector has diurnal variation, i.e., a variation of vehicle volume during the day. Below is an example of NO2 diurnal variation which has a repetition during the week [4]:

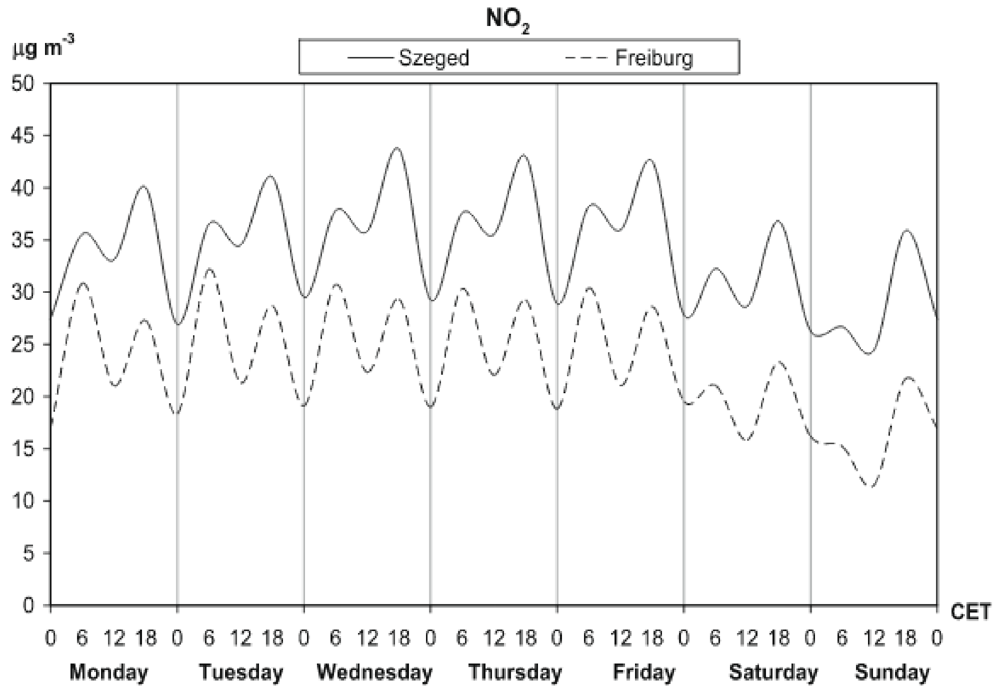


Figure 1. Diurnal variation of NO2 during one week.

Harmful secondary pollutants such as ground level ozone are also triggered by primary pollutants originating from vehicle emissions, e.g., hydrocarbons and nitrogen oxides. Generally, the majority of ground level ozone in urban areas was contributed by vehicle emissions. Additionally, airborne fine particulate can promote the risk of myocardial infarctions, strokes and heart failure. Furthermore, particle deposition in the lungs triggers the release of systemic pro-inflammatory responses.

Air pollution related to traffic is pronounced in urban areas, both in developed and developing countries. Studies on source apportionment have in many areas revealed that air pollution related to traffic is quite high. Traffic air pollution contributes 17% to 49% of urban air pollution in Indian cities [5]. In Bandung city, Indonesia, for example, roughly 60% of fine particles, including secondary aerosols, were attributed to have traffic origins [6].

In India, during a strike period when the traffic volume was considerably lower than normal, a significant reduction of ambient concentrations of BC, PM and CO (48%, 28%, and 20%, respectively) was observed [7]. As a significant contributor to worsening urban air quality, the controlling of air pollution related to traffic (both exhaust control and non-exhaust control) should be intensively promoted. The fuel consumption of vehicles can generally be estimated when we know how far a vehicle has travelled. In general, for vehicles, fuel consumption and air pollutant emissions are related to vehicle type, weight and speed. Several models have been proposed to investigate these factors, as shown in Demir [8].

Road grade was also considered an important factor for vehicle emissions [9] [10]. In Indonesia, driving pattern, particularly those of public transport drivers, are of concern due to their driving styles, which can lead to the emission of high levels of air pollutants. Fonseca [11] found that driving style was an important parameter for vehicle emissions. In general, the method for quantifying emissions from vehicle exhaust comprises two methods, i.e., on-road testing using a portable emission measurement system (PEMS) and using a chassis dynamometer in laboratory tests. On-road emission measurement has an advantage in that it may better represent real world conditions, i.e., it can handle seasonal variations, driving on different types of road materials, as well as road types (flat, ascending, descending). Air pollution emissions during vehicle operation have been researched in several studies such as Wang [12] for NOx and BC emissions, and Fuo [13] for estimating the CO, HC and NOx emissions of light duty gasoline vehicles. In the Indonesian context, the fuel consumption of vehicles related to vehicle velocity speed can be seen in the following graph [14].

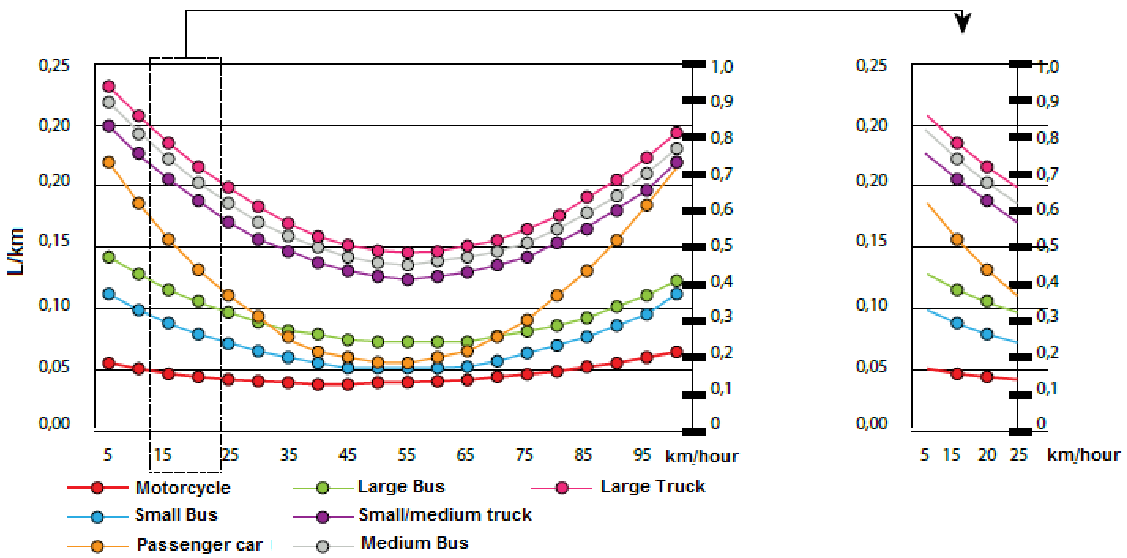


Figure 2. Specific vehicle fuel consumption related to vehicle speed.

Thus, the relationship between specific fuel consumption and vehicle speed can be derived as follow [14]:

Table 1. Specific fuel consumption and vehicle speed.

Vehicle type	Specific fuel consumption formula
Private car	7E-5x2 – 0.0077x + 0.2579
Motorcycle	1E-05x2 – 0.0009x + 0.0601
Small bus	3E-05x2 – 0.0029x + 0.1285
Medium bus	5E-05x2 – 0.0056x + 0.2961
Large bus	3E-05x2 – 0.0029x + 0.1533
Small/medium truck	5E-05x2 – 0.0053x + 0.2771
Small/medium truck	5E-05x2 – 0.006x + 0.3147

Based on Figure 2 and Table 1, the lowest emission for vehicles was achieved during medium speed, i.e., 45 km/hour to 65 km/hour. Even at low speed (around 5 km/hour), emissions were still higher than at 45 km/hour to 65 km/hour. Thus, maintaining vehicle speed while driving at roughly 45 km/hour to 65 km/hour can potentially reduce air pollution emissions. In his research, Fergusson [15], using the ERR transport emissions model estimated that 3.1% of car CO2 emissions can be curtailed if the maximum limit of 50 mph was imposed on ordinary roads.

3. Methods

A questionnaire survey was conducted to get data for technology distribution concerning the vehicle fleet in Semarang. A total of 1150 questionnaires was collected for the survey and included public transport (taxis, buses, paratransit); however, only private vehicles are highlighted in this study. Semarang consists of 16 sub-districts (*kecamatan*).

Semarang is divided into 10 city zones (Bagian Wilayah Kota, BWK). The city center is concentrated in Semarang Utara (north), Semarang Tengah (central), Semarang Barat (west) and Semarang Selatan (south). The number of registered vehicles for each district was used to allocate the number of questionnaires for each type of vehicle.

In addition to the parking lot survey, we conducted a car and motorcycle workshop survey to establish a regular maintenance figure. In this survey, we delivered 94 surveys for motorcycles and 73 surveys for personal cars. The GlobalSat DG-100 GPS Data Logger was employed for monitoring. The DG-100 GPS recorded time, traveling speed, altitude and the location of each monitored vehicle on a second-by-second basis. The output information for GPS monitoring was the driving pattern of the vehicle (including start/stop time and speed) and travel route location. In this study, GPS monitoring was conducted only for private cars.

A combination of emission factors was used to quantify emissions. No single reference was able to provide a complete emissions factor for land transportation. Additionally, a local emissions factor was not identified in this study. A list of emission factors used in this study is shown in the table below.

Table 2: Emission factors applied in this study.

Fuel	Pollutant						
	TSP (g/kg) (a)	NOx (g/kg) (a)	CO (g/kg) (a)	HC (g/mile) (b)	CO2 (g/TJ) (c)	CH4 (g/TJ) (c)	N2O (g/TJ) (c)
Gasoline	0.03	8.73	84.7	0.184	69.3	0.033	0.0032
Diesel	1.1	12.96	3.33	0.29	74.1	0.0039	0.003

Note: (a) CORINAIR (2009) (b) US EPA 1997 © IPCC 2006

4. Results

The survey was conducted in random parking lots across the Semarang districts. Average kilometers travelled for private cars was 17,737 km/year with number of machine start-up during weekdays and weekends were on average 5.19 km/year and 3.79 km/year, respectively. For motorcycles, the average kilometers travelled was 27,092 km/year with number of machine start-up during weekdays and weekends were on average 5.84 km/year and 3.98 km/year, respectively. The odometer reading for private cars showed a maximum of 3,046,509 km and a minimum of 700 km. For motorcycles, odometer reading showed a maximum of 973,164 km and a minimum of roughly 54.24 km.

Based on the survey conducted in workshops, for motorcycles, the average kilometers travelled was 9.510 km/year, while for private cars the average kilometers travelled was 21.347 km/year. The difference between VKT travelled per vehicle for the parking lot survey and workshop survey may have been due to the distribution of vehicle age, which was quite different between the two. In the workshops, relatively new vehicles (< 5 years) were identified. Semarang city has a complex terrain, where the South-North route is significantly different in terms of altitude (roughly 300 m in height), while the East-West route has relatively flat terrain.

In general, air emissions related to vehicle speed indicated that the East-West route delivered larger levels of air pollutant emissions, both in the morning and at noon, compared to those for the South-North route (see Figures 3 to 6 below). Slower speeds on the East-West route due to higher traffic volume may be the reason of this. Noon generally produced higher emissions than in the morning, which may be due to the use of private cars for more than one daily activity, e.g., lunch, meetings and relaxing. During the afternoon, pollutant emissions were generally indicated to be higher than emissions in the morning.

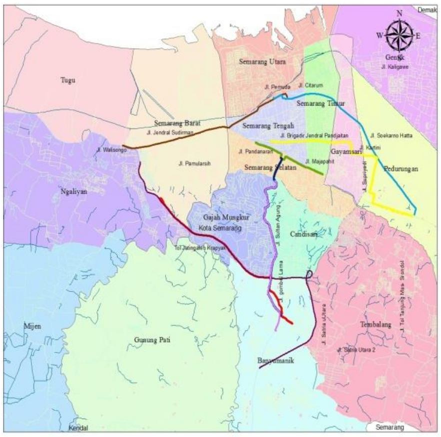


Figure 3. Car weekday routes.

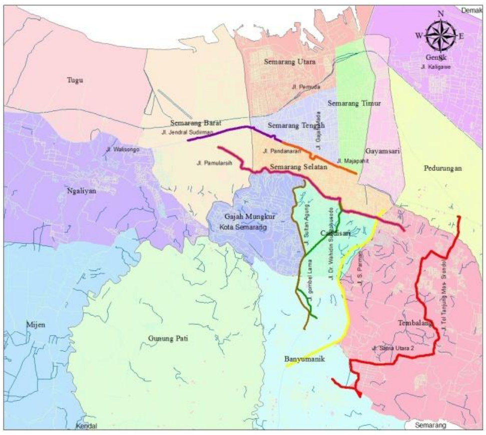


Figure 4. Car weekend routes**.**

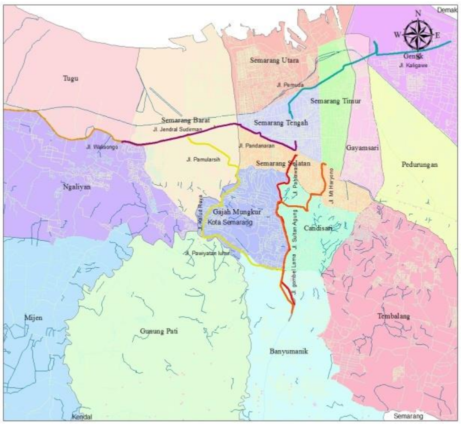


Figure 5. Motorcycle weekday routes

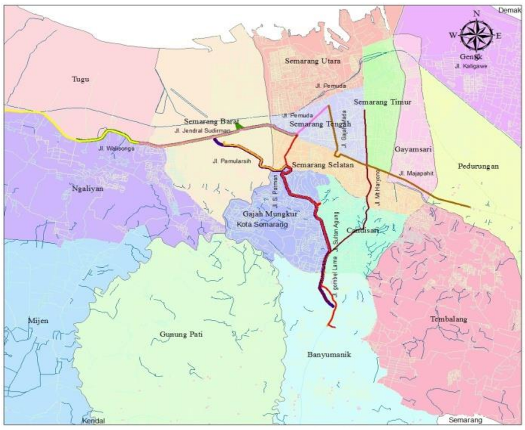


Figure 6. Motorcycle weekend routes.

Vehicle speeds occasionally dropped to almost zero, indicating traffic congestion (this figure represents morning traffic). In general, the speed of vehicles remained under 50 km/h and very rarely exceeded 50 km/h. It was difficult to reach this speed due to severe congestion during rush hour traffic in the mornings and afternoons. This speed could be reached during non-rush periods, particularly by motorcycles. Regarding the fact that the vehicle fleet continues to increase, it is likely that these conditions will worsen in the years to come. Thus, the implementation of a public transport system in Semarang is an important approach for combatting the effects this may have. An example of the relationship between vehicle speed based on routes during the morning periods is presented in the Figure 7 below.

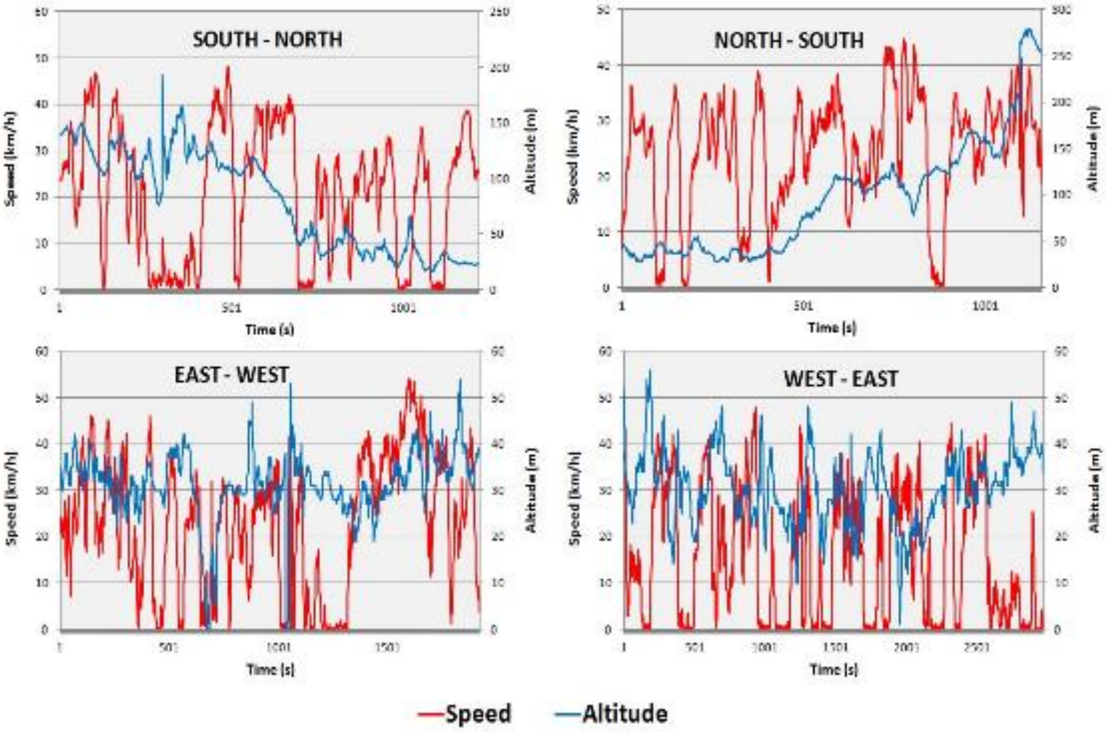
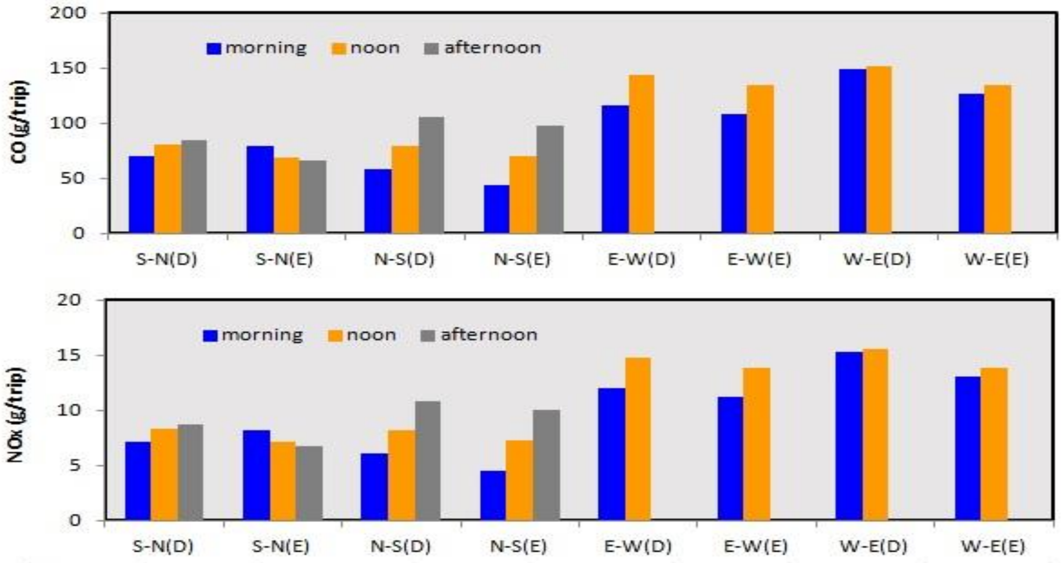


Figure 7. Altitude and time related to vehicle speed.

Based on the emissions results (see Figure 8), the East-West corridor appears to have higher emission than the South-North corridor. This is contrary to our hypothesis that vehicles travelling on the South-North corridor have higher emission rates than those using the East-West corridor. We presumed that by travelling at fluctuating altitudes, the speed of the vehicle would not reach an ideal speed on the road. In fact, traffic congestion and high vehicle volume on the road has a greater influence on emissions than the terrain differences present in Semarang city, as is shown in Figure 8. The East-West corridor connects to the Trans-Java Northern Highway, which may have an impact on this traffic congestion. Moreover, there is essentially no difference in emissions between the measurements periods, i.e., morning, noon and afternoon.

The emissions of private motorcycles is estimated to be higher than private vehicles, as the registered number of motorcycles running on Semarang roads is much higher than the registered number of cars. In 2015, registered motorcycles numbered 886,420 units, while cars were roughly 186,613 units. Based on our calculations using LEAP software (not detailed in this paper), the estimated CO emissions in 2016 for motorcycles and cars was 6.545 Mton and 19.1 Mton, respectively. Traffic arrangement through ATCS may one solution for reducing traffic congestion, which causes high levels of emission air pollution. Shifting from using a private car or motorcycle to a public transport system will have a significant impact on reducing the number of private cars and motorcycles on the road, and will therefore diminish air pollution related to traffic (exhaust and non-exhaust emissions). However, air pollution initially originated from people moving from from one area to another; as such, proper land-use planning, which can minimize people's movement, is also important for a long-term solution for reducing air pollution in urban cities.



Note: Emissions were derived from recorded speed related to fuel consumption
S: South, N: North, E: East, W: West, (D): Weekday, (E): Weekend

Figure 8. Air pollutant emissions derived from private cars.

5. Conclusion

Air pollutant emissions related to the transportation sector in Semarang city will be higher in the near future, due to the large number of private vehicles used to commute in both the city and for inter-city travel. Based on the parking lot survey, the average VKT for private cars was 17,737 km/year, while for motorcycles the average VKT was 27,092 km/year. Meanwhile, the vehicle workshops survey showed an average VKT of 9,510 km/year for motorcycles, while for private cars the average VKT was 21,347 km/year. During rush hour, the speed of vehicles was generally below 50 km/h and very rarely did the speed exceed 50 km/h. Air pollutant emissions for the East-West routes of Semarang city were generally higher than those on South-North routes, according to private car emissions. Motorcycles contribute significantly more to urban air pollution than cars. In this study, traffic congestion and traffic volume contributed more to air pollution than the impact of fluctuating terrain.

6. Acknowledgement

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