NUSANTARA BIOSCIENCE
Vol. 8, No. 2, pp. 288-296
November 2016

ISSN: 2087-3948
E-ISSN: 2087-3956
DOI: 10.13057/nusbiosci/n080225

The estimation of emission from the gateways to Surakarta City, Indonesia using the software of Mobilev 3.0 as the basis for an action plan of emission control

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Manuscript received: 5 October 2015. Revision accepted: 11 November 2016.

Abstract. *Sunarto, Wiryanto, Himawan W. 2016. The estimation of emission from the gateways to Surakarta City, Indonesia using the software of Mobilev 3.0 as the basis for an action plan of emission control. Nusantara Bioscience 8*: *288-296.* Surakarta is the center for activities of a pseudo area unit called Greater Solo, which includes several regencies nearby, bordering on Surakarta City. As a result, many commuters enter Surakarta daily, most of whom using personal vehicles, causing high emission from mobile sources especially during working days. Heavy traffic can be seen in several main gateways to the city, namely two-way traffic section of Slamet Riyadi Street, Adi Sucipto Street, Ir Sutami Street, Yos Sudarso Street and Mangunsarkoro Street. Emission from transportation on those streets is higher than that of Central Business District (CBD). The objective of this study was to estimate the emission from mobile sources on the gateways to Surakarta City as an input for an action plan to reduce urban emission. The number of vehicles on the five gateways was counted by direct observation using CCTV belonging to the Office of Transportation, Communication and Information of Surakarta City in 2012. The estimation of emission from transportation was done using software of Mobilev 3.0. Data conversion was done using Microsoft Excel. The results showed that in 2012, the total Average Daily Traffic (ADT) on the five gateways was 442,959 units of vehicles. The highest ADT was found on Ir Sutami Street, which was 110,537 units/day. Most of the vehicles were motorcycles (75%) and personal passenger cars (17%). Other gateways had similar composition, but their exact numbers varied. This composition was an obvious indicator of community preference for personal vehicles over public transportation. The estimate of emission on the five gateways was 84.87 ton/yr of CH_4, 1,829.56 ton/yr of CO, 46,212.03 ton/yr of CO_2, 946.29 ton/yr of HC/NMVOC, 190.13 of NOx ton/yr, 14.75 ton/yr of PM_{10} and 2.52 ton/yr of NH_3. The amount of emission was influenced by the number and composition of vehicles on each street. The total consumption of fuel on the five gateways was 14,884.35 ton/yr, mostly by motorcycles (34%) and personal passenger cars (29%). The composition of fuel was 61% of gasoline and 39% of diesel. Most of the time, the traffic scenario was heavy except for Ir Sutami Street and Mangunsarkoro Street in which the traffic was *stopped and go.*

Keywords: Emission, street transportation, Gateway to Surakarta, Mobilev, vehicles

INTRODUCTION

Vehicles are the main contributors of emission in urban areas because the number of personal vehicles increases due to the increased human mobility which is not supported by the availability of decent public transportation. The increased human mobility and demand for transportation is the result of economic development in the world, especially in developing countries. In addition, many governments increase the number of highways and freeways. It is not surprising that Amin (2009) predicted that the number of vehicles would multiply ten times within the period from 2008 to 2050.

The operation of vehicles, however, creates a problem, because it requires fuel. The increase in fossil fuel consumption in the transportation sector will cause emission of pollutants, detrimental to the environmental and human health. A report by EEA (European Environment Agency) in 2008 showed that land transportation was the main source of emission of almost all parameters of air quality (CO, NO, VOC and PM) except for SO_2. For carbon monoxide and nitrogen oxide, the values even reached two third of the total emission (Popescu and Ionel 2010; Gulia et al. 2014).

In Indonesia, the largest fuel consumption is found in the transportation sector (MoE 2012). Specifically for land transportation, the number of vehicles increased up to 10% in 2012, the highest among all transportation modes (BPS 2012). The growth of vehicle ownership showed an increasing trend in 2009-2011. The motorcycle is the fastest growing transportation modes. This trend also occurs in Surakarta city. The report of environmental condition in Surakarta (SLHD 2012) showed that the ownership of motor vehicles increased from 242,834 in 2010 to 279,755 in 2012, in which the highest one was motorcycle.

Surakarta City is considered to have more advanced development and progress than the surrounding regencies. This is the main attraction of Surakarta for the surrounding communities with their various interests. As a result, there are many commuters entering and leaving Surakarta City. The Office of Transportation, Communication and

Information released data in 2014 showing that the number of commuter vehicles was three times as many as that of Surakarta residents. The heavy traffic on the roads increases emission which ironically must be dealt with by Surakarta City as a consequence of its status as the center for activities (Dishubkominfo 2014).

The majority of commuters use personal vehicles, both passenger cars, and motorcycles. Public transportation is not considered convenient enough regarding safety, service and reliability of schedule. Besides, the capacity of public transportation is not sufficient for the number of consumers that need the service. It can be concluded that the quality and quantity of public transportation modes are not sufficient, so the people prefer to use personal vehicles. In fact, the central and local governments in Indonesia do not have strong regulation and control that limit the ownership of personal vehicles (Setyono et al. 2014).

A large number of commuters strengthens the assumption that the gateways to Surakarta City will be busier. During working days, a great number of commuters will enter and leave Surakarta through several gateways, such as Slamet Riyadi Street, Adi Sucipto Street, Ir Sutami Street, Yos Sudarso Street and Mangunsarkoro Street. These streets are the main gateways connecting Surakarta with the surrounding regencies.

The objective of this study was to provide data of emission from mobile sources on the gateways to Surakarta City, namely Slamet Riyadi Street (two-way traffic section), Adi Sucipto Street, Ir Sutami Street, Yos Sudarso Street and Mangunsarkoro Street. Through analyses of traffic count and emission data, the traffic characters and composition of vehicles in each gateway were known. The expected outcome is the availability of emission management plan and policy from the local government to deal with the gateways. This study will be able to encourage the local government to have communication and cooperation with neighboring regencies to manage commuters.

MATERIALS AND METHODS

Study site

The locations of the study were the gateways to Surakarta City, Central Java, Indonesia represented by Slamet Riyadi Street (two-way traffic section), Adi Sucipto Street, Ir Sutami Street, Yos Sudarso Street and Mangunsarkoro Street. The observation was conducted all year round of 2013.

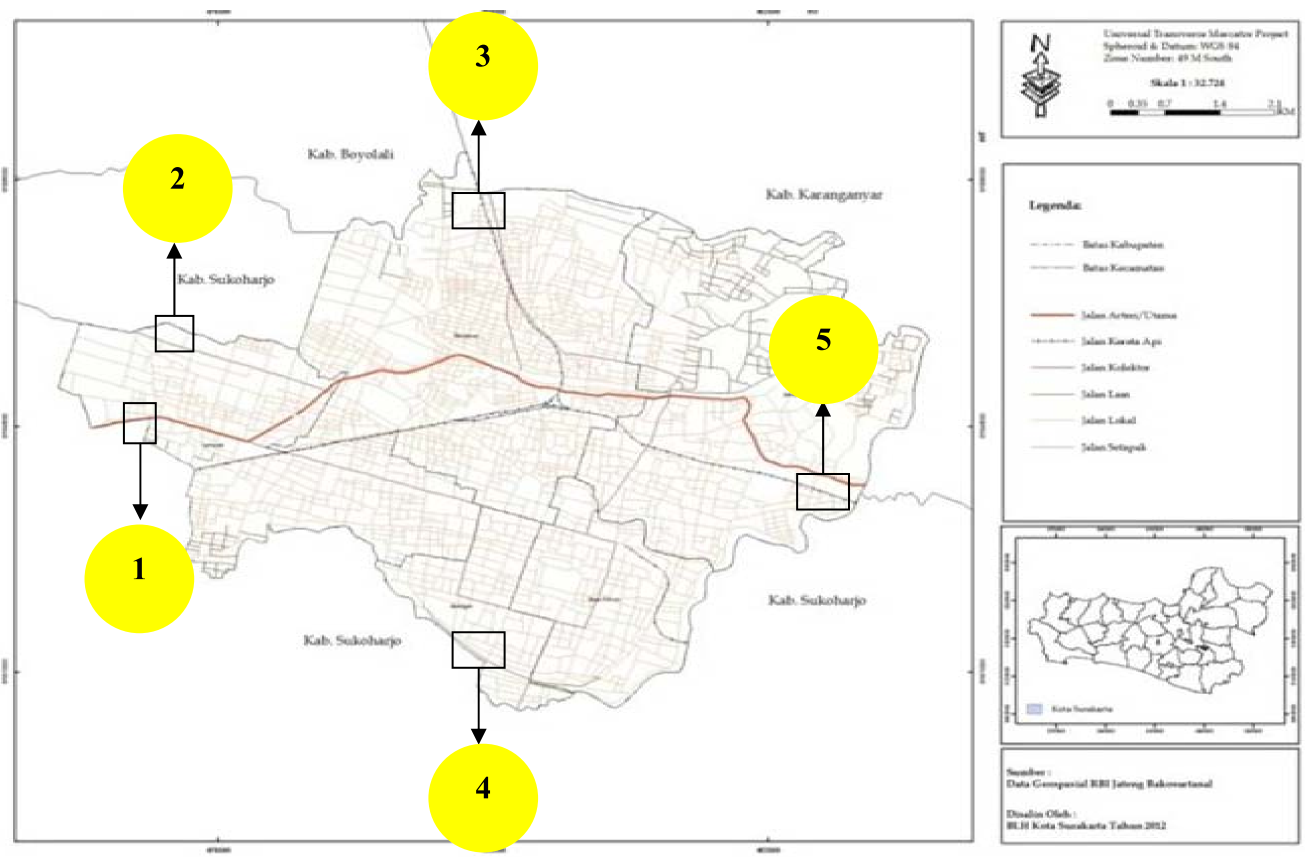


Figure 1. The site of the study area. 1. Slamet Riyadi Street (two-way traffic section), 2. Adi Sucipto Street, 3. Mangunsarkoro Street, 4. Yos Sudarso Street, 5. Ir. Sutami Street

Materials and equipments

This study used several tools: CCTV (owned by the Surakarta City Office of Transportation, Communication, and Information), handy-cams, counters, traffic count sheets, pencils and pens, a laptop having applications of Microsoft Access, Microsoft Excel, and Mobilev 3.0. The materials used were data of traffic recording on the five gateways during working days.

Data collection method

Data of traffic count were collected daily during working days on the five gateways using observation and counting methods. The traffic count was collected from the recording of CCTV set for 24 hours daily as stipulated by Indonesian Highway Capacity Manual (MoPW 1997) and Procedures for Traffic Volume Survey (MoPW 1998).

Daily traffic counts were conducted for each vehicle type, in accordance with the application of Mobile 3.0 (Fige GmbH 1997), namely: passenger car, motorcycle/scooter, light duty vehicle (gross weight of vehicle < 3.5 ton), hard duty vehicle (gross weight of vehicle > 3.5 ton, for carrying goods or minerals) and bus. Secondary data related to analyses and operation of Mobilev 3.0 were also gathered. The operation data of Mobilev were, among others, street identity (status, locations, length [m], the number of lanes and direction) and the average of vehicle speed for each street.

Data analyses

The results of traffic count were analyzed using Mobilev 3.0 to estimate the emission of parameters of CH_4, CO, CO_2, NMVOC, NOx, PM_{10} and NH_3. Mobilev 3.0 showed the characters of the road, such as traffic scenario, average daily traffic for each vehicle, and the amount of fuel consumed. The results of Mobilev analyses were discussed descriptively supported by secondary data.

Mobilev is a helpful software to facilitate the estimation of emission from mobiles sources on road. Mobilev works using the basic principle of emission calculation as follows (EMEP/EEA Corinair 2013):

$$\mathbf{E = (AD \times EF)x((100\text{-}EC)\%)}$$

Where,

E : Total emission (ton/yr)
AD : Activity Data
EF : Emission factor coefficient
EC : Efficiency of emission control technology (%)

The estimation of emission works according to the scenario used (there are 3 Tier scenarios), depending on the complexity and the availability of activity data (AD), which affect the accuracy of the estimation results. Mobilev had been set for the highest scenario (Tier 3) and all the operation requirements for the scenario had been provided automatically. Therefore, Mobilev could give more accurate emission estimation than manual calculation.

RESUTLS AND DISCUSSION

The problem of transportation in Surakarta

The jurisdiction of Surakarta is not very large with limited road networks. However, Surakarta has the status of the center for activities for neighboring regencies. The city and its neighboring regencies are collectively called the Greater Solo. This status, coupled with its strategic location in the intersection of interprovincial traffic, has caused heavy traffic especially during working days. One of the main problems of Surakarta is the mobility of commuters from the surrounding areas.

Data from the census of the Central Bureau of Statistics Surakarta in 2013 showed the population of Surakarta was ±507,825 (BPS Surakarta 2014). Data from the Ministry of Environment showed a consistent trend of increase in domestic vehicle ownership. The same trend also occurred in the neighboring regencies. The increase in personal vehicle ownership will have a positive correlation with the emission from mobile sources. Surakarta has public transportation, but only a few of the transportation modes can be considered decent enough, regarding quality and quantity. The lack of public transportation has encouraged people, including commuters, to own personal vehicles.

The number of commuters' vehicles during working days greatly exceeds that of domestic vehicles of Surakarta. Media release from the Office of Transportation, Communication and Information in 2014 mentioned that the ratio of commuters' vehicles and the domestic one was 3:1 during peak hour. This problem will get worse as Surakarta grows fast and becomes more attractive to the people from the neighboring regencies. If the high-quality public transportation modes are not available, the commuters' personal vehicles will continue to dominate the traffic of Surakarta (Dishubkominfo 2014). The Environmental Status Surakarta City of 2011 mentioned that the number domestic motorcycle in Surakarta was 279,755, so the number of total motorcycles on the road in Surakarta during working days was ± 850,000, of which ± 600.000 belong to commuters' (SLHD 2012).

The characters of traffic on gateways to Surakarta

The high intensity of commuters who use personal vehicles causes heavy traffic, especially on the gateways to Surakarta, which in turn put pressure on the environment in the form of emission from the fuel combustion from the motor vehicles. Surakarta has many gateways because it shares borders with several regencies such as Sukoharjo, Boyolali, and Karanganyar. Other regencies which do not share a border with Surakarta are located not far from Surakarta and can be easily accessed. This condition encourages commuters to enter and leave Surakarta through many streets.

Not all the gateways are main roads. Some of them are distributors and local connectors having heavy traffic during rush hour when people go and return from work/school. This study focused on the gateways classified as main roads. From road classification, five gateways considered as main roads in this study were: Slamet Riyadi Street connecting Surakarta and Sukoharjo, and at the same time is the gateway from Yogyakarta; Adi Sucipto Street connecting Surakarta and Boyolali, Sukoharjo and Karanganyar (Colomadu), and at the same time a gateway from Semarang; Yos Sudarso Street, connecting Surakarta and Sukoharjo and Wonogiri; Mangunsarkoro Street connecting Surakarta and Purwodadi and an alternative gateway from north coast of Java; and Ir Sutami Street connecting Surakarta and Karanganyar and Sragen and the main gateway from Surabaya. Daily traffic count resulted in Figure 2.

The average daily traffic showed the average number of vehicles on five gateways, observed for 24 hours. The total number of vehicles per day on the five gateways was 442,959 units. The biggest ADT was found in Ir Sutami Street (110,537 units /day) which is the main gateway from Surabaya (East Java), connecting Surakarta with settlements in Karanganyar and Sragen Regencies. The lowest ADT was found in two-way traffic section of Slamet Riyadi Street (65,825 units /day), which is the main gateway from Jogjakarta directly to central business district (CBD) of Surakarta.

The pie chart in Figure 2 clearly indicates the high number of the commuters' personal vehicles passing through the gateways to Surakarta, as shown by the high percentage of motorcycles (75%) and passenger cars (17%). Specifically, the dominant percentage of motorcycles shows the preference of people to this type of mode due to its easiness in purchase and use. This supports the data that motorcycle is the fastest growing mode of transportation not only in Surakarta but also in other cities in developing countries in general.

Table 1. Identity of gateways to Surakarta City, Central Java, Indonesia

Name of road/ Gateway	Position/connected with	Status of road	Length (m)	Number of lanes	Direction of road
Slamet Riyadi	West Gateway /Sukoharjo; main gateway from Yogyakarta and Semarang	Main road/ urban	3093	4	Two ways
Adi Sucipto	West Gateway / Sukoharjo, Boyolali, Karanganyar (Colomadu)	Main road/ urban	3617	4	One way
Ir Sutami	East Gateway /Karanganyar, Sragen; main gateway from Surabaya	Main road/ urban	1925	4	Two ways
Yos Sudarso	South Gateway /Sukoharjo, Wonogiri	Main road/ suburban	1173	4	Two ways
Mangunsarkoro	North Gateway Purwodadi	Main road/ suburban	1777	2	Two ways

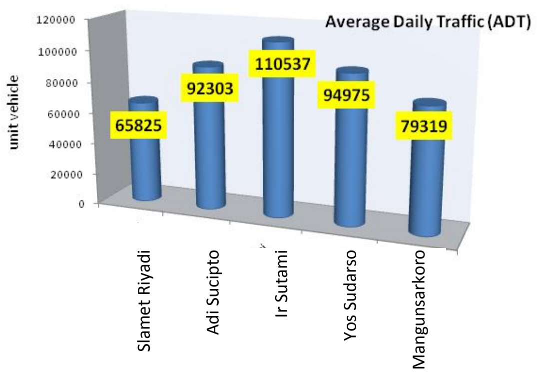


Figure 1. The average daily traffic (ADT) of the gateways to Surakarta City, Central Java, Indonesia

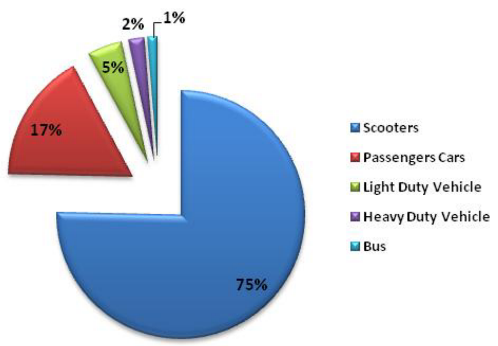


Figure 2. The composition of vehicles passing through the gateways to Surakarta City, Central Java, Indonesia

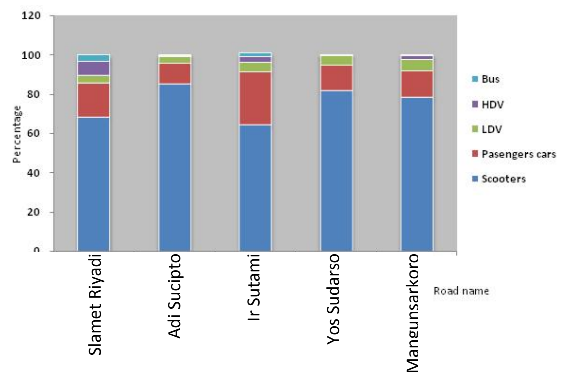


Figure 3. The compositions of vehicles on each gateway to Surakarta City, Central Java, Indonesia

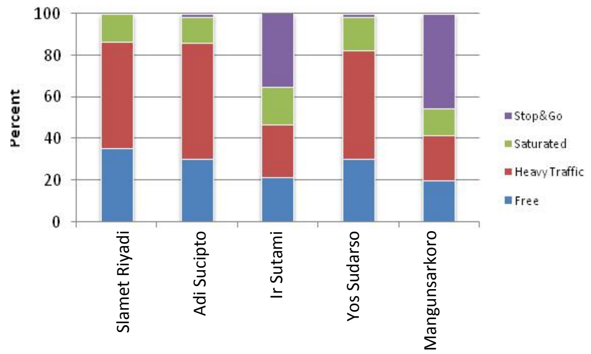


Figure 4. The traffic scenario on each gateway to Surakarta Surakarta City, Central Java, Indonesia

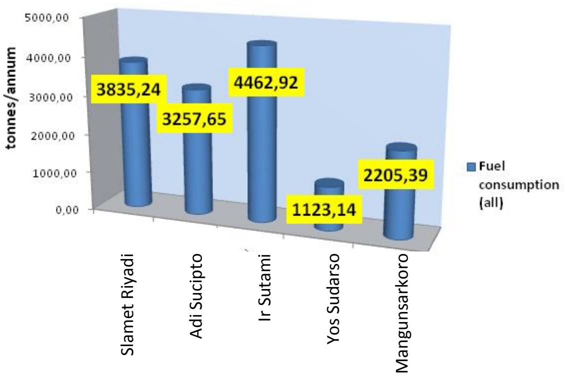


Figure 4. Consumption of fuel of motor vehicles on each gateway of Surakarta City, Central Java, Indonesia

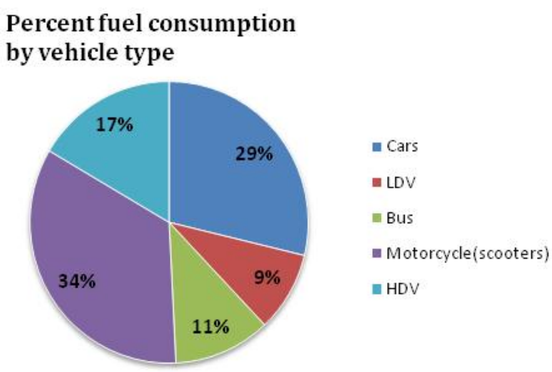
The compositions of vehicles were significantly different among the gateways. The compositions of vehicles in Adi Sucipto Street and Yos Sudarso Street were identical with motorcycle dominance, whereas in Slamet Riyadi Street and Ir Sutami Street there was an increase of passenger cars, HDVs and Buses although motorcycles were still dominant.

Adi Sucipto Street, Yos Sudarso Street, and Mangunsarkoro Street serve more as connectors between settlements in neighboring regencies and Surakarta. Therefore, the domination of personal vehicles, especially motorcycles, was very obvious. The commuters travel short distance daily to go and return from work or school. Most of the commuters choose to have houses in urban fringe located outside the jurisdiction area of Surakarta City because the distance is not too far. For the same reason, they prefer motorcycle which is more practical than cars.

Slamet Riyadi Street and Ir Sutami Street are the main gateways from other cities and provinces. Intercity and interprovincial buses, goods vehicles and passenger cars pass through these streets. There were a significant number of buses in Slamet Riyadi Street because this street is the main access to bus the station Tirtonadi, Surakarta City where the buses stop before departing to various destinations. This street also serves as the main gateway for intercity tourist buses and passenger cars coming from the west to CBD of Surakarta. Through these streets, goods vehicles are directed to avoid the heavy traffic in CBD of Surakarta.A similar condition occurs in Ir Sutami Street. But, some buses and goods vehicles are directed to Ring Road of Mojosongo before entering this street. This is the reason why the number of buses and goods vehicles (especially trucks) was not as many as those on Slamet Riyadi Street.

The analyses using application of Mobilev also produce scenarios of traffic commonly occur on road based on ADT data and the complementary data of road identity. The followings are the traffic scenarios on the five gateways resulted from Mobilev analyses. Traffic scenario gives the general pattern of traffic condition on a road. The patterns on a road may vary and can be divided into percentages. The types of scenario in Mobilev are free traffic, heavy traffic, saturated, and stop and go. Free traffic is the ideal condition on the road because the traffic flows continuously, so the idling emission due to the instability of engine combustion can be minimized. Based on the analyses, it was found that Slamet Riyadi Street, Adi Sucipto Street, and Yos Sudarso Street had mostly heavy traffic scenario. In this scenario, the traffic is dense but still flows continuously, although the speed is reduced. Based on Mobilev calculation and supported by field observation, it was found that the speed on the three streets was 30-40 km/hr. The next scenario is free traffic. The less ideal traffic scenario was found on Sutami Street and Mangunsarkoro Street. The dominant scenarios on both streets were stopped and go, and heavy traffic. The traffic on the two streets often got jammed and moved at low speed. The calculation from Mobilev showed that the average speed on the streets was 20-25 km/hr.

Using Mobilev, consumption of fuel from vehicles passing on the road can be calculated. The number and composition of vehicles influence the consumption of fuel on the gateway. The effect of the composition is related to different fuel economy value for each vehicle. Based on its fuel economy, the motorcycle is the most efficient mode, because its fuel efficiency is 35 km/liter. In addition to type and composition of vehicles, the road condition also influences fuel consumption.



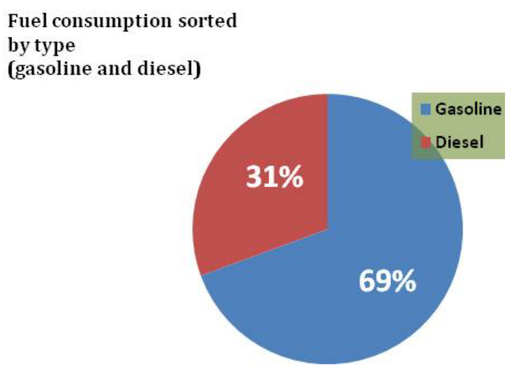


Figure 5. The percentage of fuel consumption for each vehicle type (*left*) and each fuel type (*right*) on the gateways to Surakarta City, Central Java, Indonesia

Figure 4 shows that Ir Sutami Street is the gateway where the vehicles consume the most fuel (4462.92 ton/yr), followed by Slamet Riyadi Street (3835.24 ton/yr), Adi Sucipto Street (3257.65 ton/yr), Mangunsarkoro Street (2205.39 ton/yr) and Yos Sudarso Street (1123.14 ton/yr). The composition of fuel consumption is different from the average daily traffic (ADT) in Figure 1. The difference occurs on Slamet Riyadi Street where the fuel consumption was high although its ADT was the lowest. This fact supports the opinion that vehicle composition affects the consumption of fuel.

Slamet Riyadi Street and Ir Sutami Street serve as the main road for intercity and interprovincial transportation, unlike the other three gateways which serve mostly as commuter access from the neighboring regencies of Greater Solo. The percentage of buses and goods vehicle was higher on Slamet Riyadi Street and Sutami Street than that on the other gateways where motorcycles were the most dominant. Since the fuel economy of motorcycle is better, its consumption was lower than that of buses and trucks. The consumption on Ir Sutami Street was the highest due to its high ADT and heterogeneous vehicle composition.

Unlike Figure 4 which shows the total consumption of fuel on each gateway, Figure 5 (left) shows fuel consumption for each vehicle type for all gateways. Although in determination for each road, the fuel consumption of motorcycle was affected by the percentage of bus and HDV, but the highest percentage of total consumption was found in motorcycles (34%), followed by passenger cars (29%), then by HDVs (17%), then by buses (11%), and finally by LDVs (9%). These values were closely related to fuel economy and then to the number of vehicles.

In Indonesia, in general, there are only two types of fuel, namely gasoline and diesel, but the products and distribution vary. However, in general, the two types of fuel in detailed classification still have the same emission factor. Figure 5 (right) shows the percentage of gasoline and diesel consumption. Gasoline consumption occurred mostly in motorcycles, passenger cars, and LDVs while the diesel consumption occurred mainly in HDVs and buses. Gasoline consumption (69%) was higher than diesel consumption (31%).

The composition of vehicles and the average daily traffic showed different characters on the traffic entering and leaving Surakarta. The difference affects the amount of fuel consumption, which in turn affects emission and the dominant parameter on each gateway. Therefore, management plan of emission control on gateways must take into account the traffic characters and the value of each emission parameter.

Analyses of emission on the gateways to Surakarta City

Based on the traffic count, road identity data, and complementary data of traffic, Mobilev will do the analyses and calculation of (a) traffic scenario; (b) emission value of several parameters; and (c) the consumption of fuel. Emission parameters calculated by Mobilev and analyzed in this study were CH_4, CO, CO_2, NMVOC, NOx, PM_{10} and NH_3. Several parameters such as CO, CO_2 and PM_{10} are commonly analyzed as emission from mobile sources on the road. The results of Mobilev calculation were presented in Table 2. Based on Table 2, it can be concluded that motorcycle was the main contributor of emission for parameters of CH_4, CO, CO_2 and NMVOC.

Regarding PM_{10}, combustion of fuel is not considered significant in particulate emission. The production of particulates by motorcycles is the result of road surface abrasion, tire wear, and brake wear. Unlike a motorcycle, 4-wheel vehicles are considered to be more significant in producing particulates through the combustion process, surface road abrasion, and brake wear. That is why the emission of particulates by motorcycles was lower than that of passenger cars (5.827 ton/yr) and HDV (2.693 ton/yr).

Table 2. The results of emission for each parameter (ton/yr) sorted by vehicle types using Mobilev in Surakarta City, Central Java, Indonesia

Types of vehicles	Emission Values (tonnes/annum)						
	CH_4	CO	CO_2	NMVOC	NOx	PM10	NH_3
Cars	1.170	122.141	12945.502	20.837	28.632	5.827	1.928
Light Duty Vehicles	0.792	150.331	4138.092	14.891	18.456	2.133	0.272
Buses	0.067	9.610	5324.574	2.803	54.541	1.494	0.015
Motorcycles	82.743	1528.373	15990.297	903.482	19.578	2.608	0.277
Hard Duty Vehicles	0.103	19.104	7813.567	4.275	68.923	2.693	0.029

Table 3. The estimate of emission (ton/yr) for each parameter for each street using Mobilev in Surakarta City, Central Java, Indonesia

Name of street of the gateway	Emission Values (tonnes/annum)						
	CH_4	CO	CO_2	NMVOC	NOx	PM10	NH_3
Slamet Riyadi	15.519	339.971	11973.398	174.142	66.891	4.065	0.603
Adi Sucipto	31.359	632.874	10074.751	345.659	24.883	2.996	0.657
Sutami	15.574	370.033	13855.747	176.841	64.338	4.497	0.713
YosSudarso	10.065	209.114	3456.959	111.219	8.313	1.144	0.267
Mangunsarkoro	12.358	277.567	6851.177	138.427	25.706	2.052	0.281

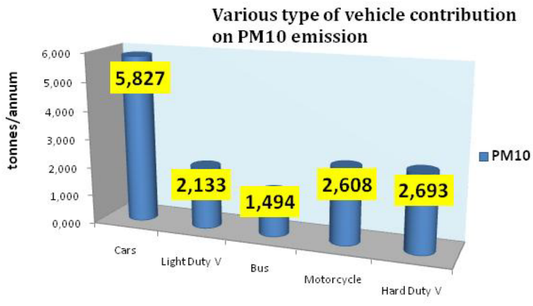


Figure 6. Emission estimation (ton/yr) of PM_{10} on gateways to Surakarta City, Central Java, Indonesia sorted by vehicle types

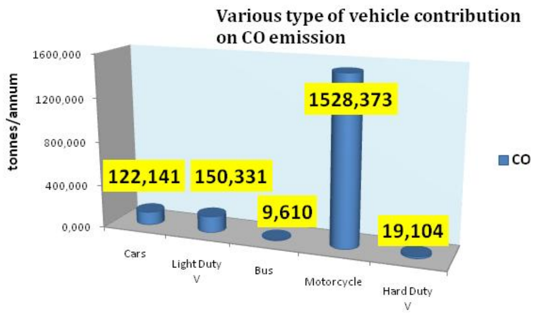


Figure 7. Estimate of emission (ton/yr) of CO on the gateways to Surakarta City, Central Java, Indonesia for each type of vehicles

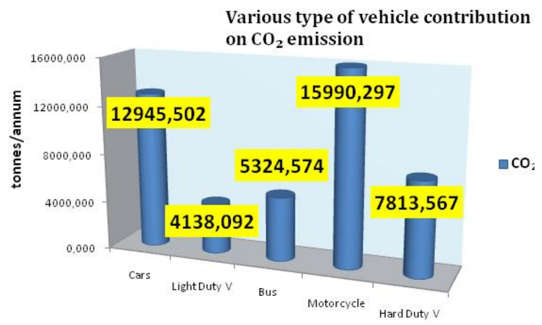


Figure 8. The estimate of emission (ton/yr) of CO_2 on the gateways to Surakarta City, Central Java, Indonesia for each type of vehicles

The emission value of PM_{10} from motorcycles was still higher than that of LDVs and buses just because of its much higher number. Emission of particulates is one indicator of urban air health. Particulates are small and widely dispersed, so they will easily enter human's body through respiration channel. Particulates often carry with them dangerous metals, so they pose a high risk to health and the environment. Heavy metals may accumulate in human tissues, causing nerve disorder and cancer. Heavy metals also damage plants and reduce the capacity of photosynthesis, so they indirectly impede plant growth (Prajapati 2012). Because of their ability to absorb particulates, plants are considered effective in reducing particulates in the air (Yang et al. 2015).

The Status of Environment in Indonesia (SLHI) in 2012 released by the Ministry of Environment stated that in Indonesia, PM pollutants pose a higher risk than other parameters. Metals found in particulates monitored in big cities include Pb, Fe, Zn, Na, Al, K and Ca, of which Pb, Fe, and Zn are produced by human activities. Lead (Pb) is an industrial pollutant, whereas Fe and Zn are produced by mobile sources (motor vehicles).

Another important emission parameter is carbon monoxide. This parameter is the main pollutant in the world, constituting 50% of the other parameters. Carbon monoxide is typical emission resulted from fossil fuel combustion, and thus represent combustion process in vehicle engines (Hill 2004)

Figure 7 shows the emission of CO sorted by modes of transportation passing through the five gateways to Surakarta City. Because CO is the byproduct of fuel combustion, the emission of CO from mobile sources on the road is slightly correlated with the number of vehicle units and their performance. The highest emission of CO was produced by motorcycles (1,528.373 ton/yr), and the lowest one by bus (9.610 ton/yr).

Carbon monoxide is related to carbon dioxide. Complete combustion produces CO_2, whereas incomplete combustion produces CO. Both result from the combustion of materials containing carbon. When the oxygen in the air is sufficient or abundant, and combustion condition is optimal, CO_2 is produced. (Hill 2004).

The two compounds have a different toxic level. Carbon monoxide is far more toxic than carbon dioxide. Carbon dioxide is one of greenhouse gasses, considered to be responsible for global warming, leading to climate change. For that reason, CO_2 emission is controlled by, among others, reducing the number of motor vehicles through various programs. Mobile sources on the road are considered the main contributor of CO_2 emission. On the gateways to Surakarta, motorcycles and passenger cars are the main contributor of CO_2 emission.

Analyses of emission were done not only for each type of vehicle but also for each gateway. The results are presented in the Table 3. The general pattern in every street shows that emission of CO_2 and CO was higher than that of other parameters. This is normal since both are the typical emission resulted from combustion of material containing carbon (vehicle fuel). Some parameters had high emission value distributed among gateways. The highest emission of CH_4, CO and NMVOC was found on Adi Sucipto Street, because of the higher proportion of motorcycles on Adi Sucipto Street than other transportation modes, especially those with diesel such as HDVs and buses.

The highest emission of CO_2 was found on Ir Sutami street (13,855.747 ton/yr), followed by Slamet Riyadi Street (11,973.398 ton/yr). The high emission of CO_2 in both street was related to the character of traffic and composition of vehicles which was more heterogeneous. In addition, the ADT value also affected the CO_2 emission, as indicated by the position of Adi Sucipto Street as the third biggest contributor of CO_2 emission (10,074.751 ton/yr). The street is having the highest emission of PM_{10}, NOx and NH_2 was Ir Sutami Street followed by Slamet Riyadi Street.

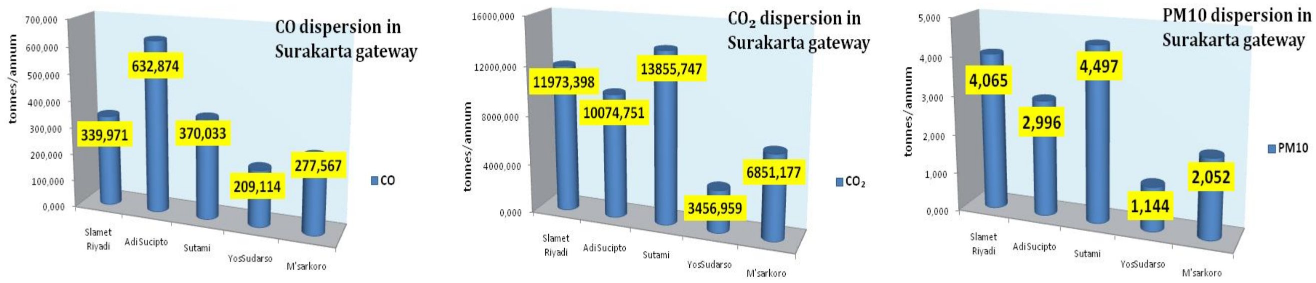


Figure 9. The emission estimate (ton/yr) of CO (upper-left), CO_2 (upper-right) and PM_{10} (low) on the five gateways to Surakarta City, Central Java, Indonesia

General discussion

In general, based on the types of vehicles, motorcycle contributed significantly on the emission of almost all parameters on the gateways to Surakarta. Out of three main parameters recorded (CO, CO_2 and PM_{10}), only PM_{10} which was not produced mainly by motorcycle. For the parameter of CO, the emission value from motorcycle was significantly higher than that of other vehicle types. For the parameter of NMVOC, the motorcycle was also dominant, because the emission of this parameter was significantly produced by vehicles using gasoline, including fugitive emission (emission produced during parking).

Different patterns emerged when analyses of emission estimate were done for each gateway. For some parameters, such as CH_4, CO, and NMVOC, the high proportion of motorcycle significantly increased emission. But the emission of CO_2 and PM_{10} was also influenced by ADT and composition of vehicles, besides the proportion of motorcycles. The conditions affecting emission depend on the characters of each emission parameter.

Considering the significant contribution of motorcycles on emission, the growth of motorcycle as the most favorite mode of transportation should be controlled or even restricted. The high emission from motorcycles and passenger cars indicated that public transportation was not optimal. The possible reason was the lack of quantity and quality of public transportation, so it was difficult for the consumer to use it. The other reason was the culture of people who are not accustomed to using public transportation.

On the gateways serving as access for commuters to work and do other activities, the motorcycles were very dominant, followed by passenger cars. The different situation occurred on the gateways serving as the entrance from certain directions. Based on this condition, it is important for the local government of Surakarta to communicate with the surrounding local governments to regulate commuter transportation. The options include the provision of decent public transportation both in quantity and quality and provision of infrastructure and facilities such as central parking lot in the border between Surakarta City and the surrounding regencies.

For Surakarta City, the commuter issue is like two sides of the same coin. It brings benefit and liability. It is beneficial because the city gets the economic benefit and human resource who drive the economy. But it is also detrimental because the city has to deal with the increasing emission in accordance with the increasing number of working people and the progress of development in Surakarta City.

Therefore, reducing the number of commuters in order to reduce emission is not a win-win solution in term of balancing the pillars of economy-environment-socio-culture to achieve sustainable development. Opening working opportunity coupled with equal development in the neighboring regencies is a wise choice to achieve the vision of Surakarta as the center for trade and tourism. The opportunity must be accompanied by the construction of infrastructure supporting the mass mobility in the form of public transportation. The followings are some solutions: (i) The provision of facilities for decent public transportation both in quality and quantity to encourage the people to use public transportation. (ii) The provision of supporting facilities for the operation of public transportation such as feeder bus, bus stops located in strategic places and central communal parking lot in the border areas. (iii) The issuance of regulation to control the ownership of personal vehicles, especially motorcycles and cars. (iv) The campaign and education to build a new paradigm that is using public transportation are good. (v) The periodic and consistent evaluation of emission in Surakarta and formulation of strategic planning of Air Quality Management specifically targeted based on the database of emission inventory and evaluation of controlling implementation.

Based on the analyses, several conclusions can be made: (i) The total emission of the gateways to Surakarta for each parameter was: was 84.874 ton/yr of CH_4, 1,829.559 ton/yr of CO, 46,212.033 ton/yr of CO_2, 946.288 ton/yr of HC/NMVOC, 190.131 of NOx ton/yr, 14.755 ton/yr of PM_{10} and 2.521 ton/yr of NH_3. Based on the gateway, almost all of the biggest emissions were found mainly on three gateways, namely Ir Sutami Street, Slamet Riyadi Street and Yos Sudarso Street. (ii) The characters of traffic on a gateway determined the amount of emission on it. The combination of high average daily traffic and heterogeneous composition of vehicles potentially caused high emission for each parameter. (iii) Personal vehicles, namely motorcycles and passenger cars, were the biggest contributors of emission for almost all parameters from mobile sources on the gateways. Motorcycles, in particular, were the most significant source and the number would keep increasing.

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