Mitigating carbon dioxide emission from mobility based on the bottom-up approach in the central business district of Surakarta City

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Abstract. The development of Surakarta as the center of economy and service in the hinterland regions adds transportation to the list of sectors generating emission and, therefore, the pressure on the environment. Such pressure comes from public preferences of private vehicles as the primary mode of transportation. This study sought to calculate the transportation emission load (carbon dioxide/CO$_2$ parameter) in the Central Business District (CBD) in Surakarta, Central Java, Indonesia. A bottom-up data was computed in Mobilev 3.0 software, which is based on the Tier III Corinair approach. Through a primary survey, this study observed 22 roads in the central economic region of Surakarta in 2014, which were equivalent to 9.38% of the total length of the road. The results showed that the emission load generated in the CBD reached 46,216.24 tons CO$_2$/year. Moreover, mobility consumed up to 15,848.82 tons of liquid fuels per year, with the largest proportion (74%) being gasoline, which is mainly used in motorcycles and private cars. In the transportation sector, the highest contributor to emission in the CBD is the use of private vehicles.

1. Introduction
Emission is a trending issue in the discussion of current environmental challenges. As a common problem, it has taken priorities in measures to achieve the Earth’s sustainability, particularly, since the positive correlation between an increase in GHG and temperature rise was publicized [1]. Moreover, emissions are directly suspected as the trigger of climate change that induces damages to natural habitats [2] and even the world food crisis [3].

Urban areas are zones of emission contributors that are also directly affected by the increasing volume of emission they produce. Surakarta is one of the cities where urban features and modern anthropogenic activities dominate nearly all of its entire region. Population growth forces people to meet their needs through a variety of anthropogenic activities that further the process of local emission release [4].

Surakarta receives additional emissions from its position as an economic and service center for the hinterland region. Inequal growth in the adjacent cities creates further traveling distance and is usually not companied by sustainable mobility strategies [5]. Referring to the problem in Surakarta, it is manifested in the intensity of commuters entering the city. Sunarto et al. (2016) [6] confirm this context as they found significant transportation activities in the intercity lane.

There are three factors internally exacerbating the emission issues of transportation in Surakarta, namely a high ratio of the addition of private vehicles, reluctance to use public transport, and dependence on fossil fuels [7]. The main factor of the use of private vehicles is expected to be in line with the results of GHG research in developing countries by Wright (2005) [8], while the use of fossil fuels in the transportation sector can support the findings highlighted in Alyuz and Alp (2014) [9].
Another weakness in mitigating local emissions in Surakarta is the lack of vegetation-covered area due to land-use change in urban regions. The vegetation cover index of this city is low (31.33), with a factual area of green open space limited to 9.72% of the total area [10]. It shows the limitations in controlling natural emissions, and therefore the efforts to reduce emissions in the short term need to focus on minimizing the potential sources of emissions and planning for the optimization of vegetated areas to absorb emissions.

This study uses Mobilev software, which has been reported as useful in estimating transportation emissions with Tier III. The emission inventory is a fundamental stage in a series of clean air management arrangements [11], along with consistent ambient measurements. Emission inventory will generate data from specific sources and period [12] and provide the basis for modeling because it presents data in more detail than ambient monitoring, including activities, distribution, and up to the pursuance of potential action plans for emission reduction [13].

The data were specifically collected from urban roads in the Central Business District (CBD) of Surakarta. CBD comprises a main intersection and traffic signals and is assumed to be a potential hotspot for emissions in urban areas [11]. Transportation is expected to focus on CBDs with the most intensive anthropogenic activities and the largest economic attraction. Based on these assumptions, the CBD is thereby projected as a region that contributes more than the other zones in Surakarta.

This study aims to estimate the emissions generated by the road transportation sector in the CBD of Surakarta. The observed emission parameter is carbon dioxide (CO₂). Aside from the amount of CO₂ released to the air, the results of this study indirectly illustrate the pressure factor on local transportation emissions.

2. Research method

2.1 Location and time
The study was conducted in March-April 2014 in the Central Business District (CBD) of Surakarta. It focused on 22 high-capacity urban roads in the district, namely (1) Honggowongso I, (2) Honggowongso II, (3) Ronggowarsito, (4) Letjend Suprapto I, (5) Letjend Suprapto II, (6) Soeharso, (7) MT Haryono, (8) Dr Moewardi, (9) Yosodipuro, (10) Soepomo, (11) Urip Sumoharjo, (12) S. Parman, (13) Bhayangkara I, (14) Bhayangkara II, (15) Agus Salim, (16) Sutarto, (17) Ki Hajar Dewantara, (18) Perintis Kemerdekaan, (19) Menteri Supeno, (20) Gatot Subroto I, (21) Gatot Subroto II, and (22) RW. Monginsidi.

2.2 Tools and materials
The daily traffic calculation utilized the CCTVs of the Transportation Agency and the private installation of surveillance cameras on the observed tracks. The number of vehicles passing through these roads was counted using a counter and a worksheet as media for documentation, while the total length of the road was calculated using Google Earth. As for the transportation emission, it was estimated in the Mobilev software, and then the results were tabulated and processed in Microsoft Excel.

2.3 Data collection
For estimating the transportation emission, the data were collected using a bottom-up approach (i.e., primary survey) on the observed roads in the CBD of Surakarta. These primary data were the average daily traffic (ADT), which was directly grouped into clusters of vehicles: motorcycles, passenger cars, light-duty vehicles (LDV), heavy-duty vehicles (HDV), and buses. Aside from ADT, other primary data included road length, road gradient, road status and location, number of lanes, and traffic directions. Meanwhile, the secondary data were expert judgments on the composition of fuel use (gasoline and diesel) in passenger cars and LDV groups. Overall, the primary data is required in the calculation of emission in Mobilev 3.0 software.
2.4 Data analysis
Primary data related to average daily traffic (which was divided into vehicle groups) and road characters were used as the basis for emission calculation in Mobilev 3.0 software. The software integrates traffic scenarios and vehicle composition representing the local conditions for emission modeling. For this reason, it meets the prerequisites for Tier III computation. This process produces annual kilometers traveled (or Vehicle Kilometer of Traveled-VKT), fuel consumption, traffic scenarios, and estimated carbon dioxide emissions. All of these results appeared in each vehicle group, which were later reprocessed in Microsoft Excel to obtain the volume of annual emissions. Afterward, these results were analyzed descriptively and presented in simple tables, graphs, and pie charts.

3. Results and discussion
The emissions in Surakarta are soon characterized by modern urban features as the product of dominant anthropogenic activities in the city. These activities are identified by the growing economies and services that operate using fossil fuels and electricity in large quantities. Such a condition elevates the potential for carbon dioxide emissions as the result of perfect combustion.

Table 1. Data of the urban roads in the CBD of Surakarta and their characteristics

| No | Road Names          | Average daily traffic (unit/day) | VKT (km/year) | Length (m) | Number of lanes | Directions |
|----|---------------------|---------------------------------|---------------|------------|-----------------|------------|
| 1  | Honggowongso I      | 54313                           | 8861502.52    | 447.23     | 2               | One-way    |
| 2  | Honggowongso II     | 54229                           | 17339131.7    | 875.66     | 2               | Two-way    |
| 3  | Ronggowarsito       | 63358                           | 42112078.7    | 1821.17    | 2               | One-way    |
| 4  | Letjend Suprapto I  | 79319                           | 25795825.1    | 890.64     | 2               | Two-way    |
| 5  | Letjend Suprapto II | 40551                           | 8673399.92    | 585.99     | 2               | Two-way    |
| 6  | Soeharso            | 35546                           | 13350600.2    | 1028.64    | 2               | Two-way    |
| 7  | MT Haryono          | 39027                           | 17079558.9    | 1199.44    | 2               | Two-way    |
| 8  | Dr Muwardi          | 91589                           | 25974969.8    | 777.4      | 4               | Two-way    |
| 9  | Yosodipuro          | 38965                           | 23921904.8    | 1681.94    | 2               | Two-way    |
| 10 | Soepomo             | 31173                           | 10718315.3    | 942.12     | 2               | Two-way    |
| 11 | Urip Sumoharjo      | 91792                           | 44660866.4    | 1333.08    | 4               | Two-way    |
| 12 | S. Parman           | 29392                           | 14214729.6    | 1324.78    | 2               | One-way    |
| 13 | Bhayangkara I       | 18140                           | 3396671.11    | 512.97     | 2               | Two-way    |
| 14 | Bhayangkara II      | 63089                           | 18744239.3    | 814.41     | 2               | Two-way    |
| 15 | Agus Salim          | 54189                           | 15664941.4    | 792.17     | 2               | Two-way    |
| 16 | Sutarto             | 110537                          | 46922509.9    | 1163.3     | 4               | Two-way    |
| 17 | Ki Hajar Dewantoro  | 29330                           | 11765409.4    | 1099.47    | 2               | Two-way    |
| 18 | Perintis Kemerdekaan| 29228                           | 7979746.44    | 748.22     | 2               | Two-way    |
| 19 | Menteri Supeno      | 29217                           | 10642967.7    | 998.12     | 2               | Two-way    |
| 20 | Gatot Subroto I     | 53596                           | 8294539.93    | 423.74     | 4               | One-way    |
| 21 | Gatot Subroto II    | 54274                           | 17591434.5    | 887.53     | 2               | Two-way    |
| 22 | Monginsidi          | 54274                           | 38411927.3    | 1939.27    | 2               | Two-way    |

Source: Primary data analysis, 2014

The profile of activities in Surakarta revolves around the limited areas of rice fields and large industries. On the other side, Surakarta is the service and economic center of an area known as the Greater Solo (Subosukowonosraten). Since the pattern of public transportation behavior shows a dependence on private modes and limited availability of public transportation between regions
(especially in quality), the potential for commuters and their transportation activities to produce emissions is considerably high. It worsens the internal conditions of Surakarta where limiting the ownership of private vehicles and dealing with reluctance to use mass transportation and invasion of online transportation have been challenging.

This research investigated 22 urban roads located in the CBD of Surakarta. The site selection was based on the assumption that with CBD acting as the local center of economy and trade, it attracts a high intensity of transportation. Table 1 shows the results of the data collection and the characteristics of the 22 roads.

All major roads observed in this study have the status of a main urban route and are located at an urban center. Some of them are vital connector roads with urban fringe areas. The total length of these roads is 22.3 km or equivalent to almost 10% of the entire stretch of the road in Surakarta (including local or minor roads).

Based on the calculation results, the average daily traffic (ADT) of the observed roads was 1,145,128 units/day. The three roads with the highest ADT were Jl. Sutarto (110,537 units/day), Jl. Urip Sumoharjo (91,792 units/day), and Jl. Dr. Muwardi (91,589 units/day). Each of them has a unique factor that attracts high traffic density, including close distance to the market or trade center and the function of inter-city lane (Jl. Urip Sumoharjo) and close distance to the service or education center (Jl. Dr. Muwardi).

![Figure 1. The composition of ADT based on the group of vehicles](image)

Based on the type of vehicle (Figure 1), the daily traffic was dominated by motorcycles and passenger cars, primarily ones that were privately owned by the public. The combination of both modes composed the most substantial proportion of ADT in the CBD of Surakarta, that is, 93%. From the perspective of mobility, this condition is alarming considering that both motorcycles and passenger cars are practically privately-owned vehicles. Besides, it occurs in the CBD that incidentally has adequate access to public transportation services.

Surakarta itself has public facilities called BST (short for Batik Solo Trans) and public means of transportation as the feeder. Not only does the Government of Surakarta City provide quality public transportation, but it also complements it with pedestrian-friendly lanes and humane bus stops.

Mobilev software allows the estimation of real fuel consumption on the observed roads. This estimate involved the computation of annual kilometers traveled (VKT), the fuel economy of each type of vehicle, and traffic scenarios. In Surakarta, the means of transportation mainly use liquid fuels like gasoline and diesel. Based on the estimation in Mobilev software, the total gasoline consumption on the observed roads was up to 11,722.72 tons/year (equivalent to 73% of all liquid fuel consumption), while
for diesel consumption, it reached 4,126.1 tons/year. Regardless of the fuel types, the total use of liquid fuel for transportation on the observed roads (the CBD of Surakarta) amounts to 15,848.82 tons/year.

![Figure 2. The composition of liquid fuel users in the transportation sector in the Central Business District of Surakarta City](image)

Separating the means of transportation according to types of liquid fuels showed that the most consumptive and most significant contributor to carbon dioxide emission in the CBD of Surakarta were motorcycles and passenger cars. Both of these modes used up to 72% of the total fuel consumption in the transportation sector (Figure 2). Once again, this condition proves that the people of Surakarta still carry out their mobility by depending on privately-owned vehicles.

Based on fuel consumption, fuel type, and vehicular technological approaches, the Mobilev software calculates carbon dioxide emissions from a vehicle. This calculation showed that the emission released from the anthropogenic activities in the CBD reached 46,216.24 tons CO₂/year. This value represents the 22 observed urban roads and is limited to areas perceived as the CBD of Surakarta City. Surprisingly, the roads selected in this study only illustrate 10% of the road transportation conditions in the city. If the emissions of all roads are taken into account, the volume of the generated emissions multiplies greatly, although the proportion is expected to be lower than the conditions in the CBD (including minor roads or local roads in the calculation).

The comparison of each observed road showed that three roads produced the highest carbon dioxide emissions, namely Jl. Sutarto, Jl. Ronggowarsito, and Jl. Urip Sumoharjo (Figure 3). Each of these three roads has different attracting factors as the center for transportation mobility, namely the establishment of economic centers, access to areas outside the city, and the main lane to create opposite direction from the other lanes. Based on the composition of average daily traffic, these three roads have different characters in access for passing HDV, particularly, Jl. Ronggowarsito on which HDV is prohibited. They have the same general trend, i.e., the dominance of motorcycles and cars.

The estimation showed that the main contributor to carbon dioxide emissions in the CBD area of Surakarta City was mobility using motorcycles and cars. Both modes are typically privately-owned. This finding is consistent with the increasing trend of local private vehicle ownership in the hinterland regions.

During a focus group discussion (FGD) on GHG in 2019, the One-stop Administration Services Office (Samsat) of Surakarta affirmed that new vehicle ownership reached 50 units of motorcycles per day and 25 units of cars per day [7]. From a temporal perspective, this condition persists with a tendency to increase in the subsequent years. As a result, carbon dioxide emissions are difficult to suppress.
The availability of adequate public transportation (Figure 4) proves that prevention or reduction of emissions must infiltrate all environmental aspects. There is no single effective solution for controlling emissions [14]. The overall pattern of community mobility needs to change to reduce emissions from the urban transportation sector [15].

![Figure 3. The comparison of carbon dioxide emissions on the observed major roads](image)

![Figure 4. Several choices of public transportation in Surakarta, including the commuter train Batara Kresna that facilitates the commuter activities from Sukoharjo and Wonogiri (left) and the interior condition of Batik Solo Trans (BST)](image)

In the case of Surakarta City, the socio-culture of the community has not been able to entirely accept the availability of public transportation and make it as their preference for mobility, even though these
public modes are in good quality and very decent condition. Preference for privately-owned vehicles is somewhat entrenched because it is considered to be more practical than public transportation. Actions on transportation management and emission control seem to have focused on physical development only but have not extended to the cultural aspects of the community’s environment. This situation results in subtle rejection from the public, as apparent from the low interest in using the provided public transportation.

4. Conclusion
The estimated carbon dioxide emissions from the transportation activities in the Central Business District (CBD) of Surakarta City amount to 46,216.24 tons CO2/year. Private ownership and the dominant use of motorcycles and cars are found to be the main contributor. This study recommends a mitigation measure that can reduce the emissions of the transportation sector in this city, that is, to improve the community’s culture as a counterweight to the provision of public transportation facilities by the government.

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