Top-Down and Bottom-Up Method on Measuring CO_2 Emission from Road-Based Transportation System

(Case Study: Entire Gasoline Consumption, Bus Rapid Transit, and Highway in Jakarta, Indonesia)

Metode *Top-Down* dan *Bottom-Up* Dalam Pengukuran Emisi CO_2 dari Sistem Transportasi Darat Berbasis Jalan

(Studi Kasus: Konsumsi Bahan Bakar Total, *Bus Rapid Transit*/BRT, dan Jalan Tol di Jakarta, Indonesia)

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ABSTRAK

Sistem transportasi darat berbasis jalan di Jakarta memberikan kontribusi tertinggi dalam inventarisasi emisi CO_2 DKI Jakarta sebesar 45% dengan jumlah 19,61 juta ton CO_2 pada tahun 2005. Meskipun ada beberapa strategi pada berbagai peraturan, kebijakan, dan kegiatan yang mengarah pada pengurangan emisi CO_2, tata kelola hal-hal tersebut terpecah dalam hal mendefinisikan metode yang dapat diandalkan dalam mengukur emisi CO_2 dari sektor transportasi berbasis jalan darat. Pendekatan *top-down* yang digunakan pada tahun 2005 tampaknya tidak valid untuk digunakan pada masa mendatang. Sementara itu, menggunakan metode yang sama pada tahun 2015, emisi CO_2 meningkat 270% dan mencapai hampir 50 juta ton CO_2. Karena data jarak tempuh kendaraan (VKT) tidak memadai, tesis ini memperkirakan emisi CO_2 dari 379 km jalan di Jakarta, yang terdiri dari 139 km jalan tol dan 240 km jalur BRT, menghasilkan sebanyak 15,21 juta ton CO_2 pada tahun 2015. Perhitungan ini hanya mencakup 6% dari total jalan di Jakarta. Meskipun, hal ini hanya bagian integral dari seluruh perhitungan emisi CO_2 dari transportasi darat, jumlah ini mencapai 30% dari hasil *top-down*. Penulis juga melakukan studi banding dengan Beijing dan New Delhi. Indonesia tertinggal di belakang Cina dan India dalam menerapkan standar emisi kendaraan. Dalam mengembangkan metode yang tepat pada perhitungan emisi CO_2 sektor transportasi berbasis jalan darat; data yang memadai harus sering direkap. Beijing dan New Delhi berada di garis terdepan dalam hal data VKT, sementara Jakarta masih dianggap menggunakan data konsumsi bahan bakar (pendekatan *top-down*).

Kata kunci: transportasi darat, emisi CO_2, konsumsi bahan bakar, jarak tempuh kendaraan (VKT)

ABSTRACT

The road-based transportation system in Jakarta contributed the highest rank on the inventory of city's CO_2 emission as much as 45% with the amount of 19.61 million ton CO_2 in 2005. Although there were some ample strategies on the various regulations, policies, and projects that led to a reduction of CO_2 emission, the governance of those plans are scattered in term of defining the reliable method on measuring traffic-related CO_2 emission. The top-down approach that utilise in 2005 seemed not valid to be used in the future. Meanwhile, using the same method in 2015, the traffic-related CO_2 emission increased 270% and reached almost 50 million tons CO_2. Due to the inadequate vehicle kilometer travelled (VKT) data, this thesis estimates the CO_2 emission from 379 km roads in Jakarta, consisting of 139 km of highway and 240 km of BRT lanes, resulted as much as 15.21 million tons CO_2 in 2015. This calculation only covers 6% of the total road in Jakarta. Although, it is only an integral part of the whole CO_2 emission inventory form road-based transportation, this number reaches 30% from the top-down result. The author also did the comparative study with Beijing and New Delhi. Indonesia is lagging behind China and India in implementing the vehicle emission standards. In develop precise method on traffic-

related CO_2 emission; the adequate data should be recorded frequently. Beijing and New Delhi are in the forefront in term of VKT data, while Jakarta still deemed to utilise the gasoline consumption data (top-down approach).

***Keywords**: road-based transportation system, CO_2 emission, gasoline consumption, vehicle kilometer travelled (VKT)*

1. INTRODUCTION

1.1 Research Background

The urban transport system in Jakarta contributed the highest rank on the inventory of city's CO_2 emission. This sector emitted a portion of 45% with the amount of 19.61 million ton CO_2 in 2005. The road-based transport sector in Jakarta must be responsible for the share of 95%, which mostly derived from high inefficient combustion from fossil fuel in the road. Meanwhile, in comparison with the GHG generation from national transportation, the transportation sector in Jakarta contributed the percentage of 24%.

Inarguably, the author believed that high shares of private vehicles in the city-induced this present figures. The number of registered private cars and motorcycles grew at a pace of roughly 10% per year in the last five years, reached a total number of 11,949,280 motorcycles and 3,010,403 cars(1). This number covered 662 km^2 Jakarta's area with the condition of 98% private vehicles serving 44% trips and only 2% public transport vehicles serving 56% trips(2). On the other hand, the growth of road development in Jakarta was meagre at 0.01 % per year(3). As a result, the consequences directly related to traffic congestion that led to the inefficiency of fossil-fuel combustion in the city. Also, Transportation Agency of DKI Jakarta Province (2010) estimated the inefficient fossil-fuel use as much as 10 trillion IDR (~667 million EUR)(4).

The preference of private vehicle use is also affected by lack of public transport integration and its capacity as well as the bad quality of public transport vehicles. The awareness to provide better public transport in Jakarta started in 2004 when the local government launched the first BRT corridor in the city. The promotion of public transportation is believed as one of the strategies to reduce CO_2 emission. Technically, the increased sharing on public transport that serving a certain number of urban trips may lead reducing CO_2 emission. Also, recently, the local government had an integrated transportation master plan, which included some effort to increase modal share of public transport in the city.

Although there were some ample strategies on the various regulations, policies, and projects that led to a reduction of CO_2 emission, the governance of those plans are scattered in term of defining the reliable method on measuring traffic-related CO_2 emission. This technique will help to get the precise assessment of CO_2 generation in the urban transport sector.

By 2005, the top-down method (gasoline consumption) was used for the calculation of traffic-related CO_2 emission in Jakarta(16). This circumstance is due to the only available and accurate input is the data that provided by Oil and Gas State-Owned Company, PT. PERTAMINA. This method is purely relied on the total sales of gasoline by the state-owned company (by that time, the state-owned company as a single seller in gasoline products). This method assumed that the gasoline consumption covers the entire gasoline that sold in Jakarta. There is no consideration that the inhabitants from outside Jakarta will consume the gasoline. Furthermore, the gasoline-consumed vehicles seemed not be the whole day in Jakarta because the traffic pattern in Jakarta is dominated by the commuter purpose (daily trip from suburban to Jakarta).

Currently, this method seemed not valid to calculate the traffic-related CO_2 emission. Firstly, there are Shell and Total as a competitor for the state-owned company in selling the gasoline in Jakarta. The data availability from both foreign enterprises seemed hard to obtain. Whereas, this data is a primary input for this method. Secondly, to get the accurate assessment, many practitioners are looking forward to the process of traffic analysis and vehicle kilometre travelled. Thirdly, since 2010, Ministry of Environment has published the regulation on the guideline of CO_2 emission calculation in national and city scale. It stated that the method used for the calculation of traffic-related CO_2 emission depends on what data are being available in city scale. Furthermore, the national CO_2 inventory derives from the accumulation of city's CO_2 emission.

1.2 Research Statement

In the context of traffic-related CO_2 emission measurement problem, the research statement is how top-down and bottom-up method measure CO_2 emission from road-based transportation system in Jakarta.

There are three objectives that in line with answering the research question. The first aim is to analyse existing methods for measuring traffic-related CO_2 emission. Secondly, this thesis tries to understand what Jakarta's effort to reduce the traffic-related CO_2 emission based on the national/local regulations/projects. Then, thirdly, this thesis tried to develop precise method on measure traffic-related CO_2 emission in Jakarta. For the government, this research gives a comprehensive review on measuring traffic-related CO_2 emission calculation in Jakarta. It can be used as a recommendation for measuring CO_2 emission in future from the road-based transportation sector in Jakarta.

The hypotheses in this thesis are (i) the author believed the top-down approach (gasoline consumption) is not reliable to measure traffic-related CO_2 emission in Jakarta, (ii) the traffic-related CO_2 emission is profoundly influenced by related attributes, such as vehicle kilometre travelled (VKT), gasoline consumption, and CO_2 emission factor, (iii) the governance of Jakarta's efforts to reduce the traffic-related CO_2 are scattered in term of CO_2 estimation in future, and (iv) the combination of top-down and bottom-up approach will lead to achieve precise assessment on measuring traffic-related CO_2 emission in Jakarta.

This thesis could not consider the CO_2 emission that generated by commuter line train and other urban transport vehicles that used electricity as primary power. In Indonesia, the method on measure train or other electric vehicle-related CO_2 emission is different because the electricity source is derived from power plants which most of them use coal. This differences also impact on the sub-category of CO_2 emission generation. The road-based transportation sector is categorised as a transportation emission, while commuter line train and other vehicles that used electricity as a primary power are classified as one part of energy emission.

Due to time constraint, this thesis also does not calculate the entire emission from road-based transportation. This thesis only provides the overview of the method on measure traffic-related CO_2 emission, the CO_2 estimation from a top-down approach (gasoline consumption) and bottom-up approach (VKT in highways and VKT for BRT lanes), analyse the reliable method that proper to Jakarta's situation, and develop the precise assessment. This sub-section will be one of the inputs in the last chapter on further research possibilities.

2. METHODS

Air pollutant loads can be estimated by direct measurement and indirect/statistic measurement. Direct measurement methods, such as source testing and continuous monitoring are usually chosen because the technique shows the amount of actual pollutant load from the polluted source that being measured(18). However, direct measurement seems challenging to estimate traffic-related CO_2 emissions in the transportation sector. This situation is due to the emission sources that mobile and in large quantities. According to Hao *et al*.(5), traffic-related CO_2 emission can be estimated by indirect calculation through statistic data although there are certain limitations in the selection of emission factors, the actual field data, and other variables. Table 29 in the appendix shows the various methods in estimating traffic-related to CO_2 emission.

Based on the condition mentioned above, in this thesis, the exhaust emission from motorised vehicles can be estimated by three approaches:

2.1 Gasoline Consumption (Top-Down Approach)

This method was used in 2005. The primary input is the data that describes the total activities that caused air pollution emission in designated geographical areas, such as total fuel sales or entire road length. 'Both are related to emission factors that are defined as air pollutants load per fuel consumed or per kilometre travelled'(15). This approach has disadvantages. One of them is regarding the total emission distribution (disaggregation). This amount is being assumed that the air pollutant load is proportional to the variables in the same geographical distribution from the related pollution activities, such as the number of population and the road length per unit area.

The estimation of traffic-related CO_2 emission through gasoline consumption assumes that the performance of gasoline on each vehicle machine is typical for every litre of gasoline consumed. The total sales of gasoline per year are converted into energy content (Joule), using the default coefficient from CANMET laboratory[11]. The formula used in this approach as follows:

$$\text{Energy Content (MJ)} = \text{Amount of Gasoline/CNG (litre)} \times \text{The Coefficient Factor (MJ/litre)} \ldots\ldots(1)$$

$$\text{Total Emission (kg CO2)} = \text{Energy Content of Gasoline/CNG (MJ) x The CO2 Emission Factor (kg/TJ)} \ldots\ldots(2)$$

This approach is a simple method to estimate the average CO_2 emission load for each type of vehicles. This approach assumed that the gasoline consumption covers the entire gasoline that sold in the city. There is no consideration that the inhabitants from outside the city consume the gasoline. Furthermore, in case of a metropolitan city like Jakarta, the gasoline-consumed vehicles seemed not be the whole day/whole trip within the city because the traffic pattern is dominated by the commuter purpose (daily trip from sub-urban to the city centre).

In a more detailed approach, the calculation is based on other several parameters, such as the road length, volume of traffic flow, vehicle speed, and the internal factors of the vehicle (the age of the motorised vehicle, the maintenance level of the motorised vehicle, and energy capacity and its cylinder).

2.2 The Volume of Traffic Flow (Middle Approach)

This approach begins with local data units, such as the amount of traffic flow at each road segment. To estimate the total emissions for a dedicated geographic area, all pollutant loads at each road segment are summed. If the amount of road is too much as well as the road length is too long, the traffic flow can be considered from the main targeted roads as a sample. This data can be assumed as an aggregate/average from the entire street in the city. Thus, the primary data requirements in this approach include:

a) Traffic counting/flow (total each type of vehicles per hour/day/week/month/year) in the main targeted roads as a sample/entirety
b) Total length of the street/road that surveyed by the traffic counting/flow
c) Entire length of main street/road in the city

The formula that used in this approach as follows

$$\text{The Total Emission (gram CO2 per km)} = \text{Average Amount of Vehicles Type A per Hour x Specific Gasoline Consumption per Vehicles Type A (litre km) x road length (km) x Emission Factor (gram/litre)} \ldots\ldots(3)$$

Whereas, the specific gasoline consumption per each type of vehicles is default based on Ministry of Transportation[17], stated in litre/km.

2.3 Vehicle Kilometer Traveled (VKT) (Bottom-Up Approach)

This approach is quite intricate and detailed. To produce the VKT, many scholars conducted several estimations, which include:

a) Matrix of origin-destination (OD)
b) Field survey on travel behaviour, which can be home-based (origin) or workplace-based (destination). At least, the primary data that being asked include the daily distance trip, the gasoline consumption, the age of vehicle engines, vehicle maintenance, vehicle engine capacity, and total each kind of vehicles (either a sample or the entire vehicle that both represented to each single inhabitants/ households)
c) Modelling to estimate the aggregation and disaggregation of VKT

Also, further analysis through this approach can describe the spatial analysis on the traffic-related CO_2 emission by line source and area source. The formula that used in this method as follows

$$\text{The Total Emission (kg CO2)} = \text{The Accumulation of VKT per Vehicles Type A (km)x Specific Gasoline Consumption per Vehicles Type A (litre/km) x Emission Factor (gram/litre)} \ldots\ldots(4)$$

Whereas, the specific gasoline consumption per each type of vehicles is default based on Ministry of Transportation [17], stated in litre/km.

3. ANALYSIS

Until recently, there are no official data regarding the entire vehicle kilometre travelled (VKT) in Jakarta. But, since 2012, PT. Jasa Marga, the highway operator in Jakarta, mentioned the average VKT inside the highways reached 40 km/day for private vehicles and 35 km/day for diesel-driven vehicles (bus and truck). Also, ITDP Indonesia[7] mentioned the average VKT for BRT coaches reached 166 km/day/bus.

This daily VKT can be used into the estimation of traffic-related CO_2 emission in Jakarta. However, it is only an integral part of the whole CO_2 emission inventory form road-based transportation. It's excluding CO_2 emission from all motorcycles trip and non-highway traffic. Meanwhile, traffic-related CO_2 emission that based on entire VKT in the city will generate precise estimation.

As described in previous chapter, the estimation of traffic-related CO_2 emission can also be tracked by the gasoline consumption although there was inadequate data from foreign fuel companies and CNG stations. According to PT. Pertamina(8), the gasoline and diesel consumption in 2015 reached 20 million kiloliters and 0.7 million kiloliters respectively. The author used the top-down approach to calculate the estimation of CO_2 emission. The first step is converting the fuel volume into energy consumption by multiplying with the energy content as calculated in Table 1 below.

Table 1: Gasoline and Energy Consumption from Road-Based Transportation in Jakarta in 2015

No.	Gasoline	Volume (litre)	Energy Content (MJ/litre)	Energy Consumption (MJ)
1.	Gasoline	19,853,333,000	34.66	688,116,521,780
2.	Diesel	679,223,000	38.68	26,272,345,640

Source: PT. PERTAMINA, 2016 and Analysis, 2017.

Then, after deriving the energy consumption (stated in Mega Joule), the author calculates the estimation of CO_2 emission by multiplying with each CO_2 emission factor. According to the top-down approach calculation, the traffic-related CO_2 emission reached almost 50 million tons CO_2 in 2015. This figure increased 270% in comparison with the data in 2005 through the same approach. Currently, this technique seemed not just as single step calculation as in 2005. This condition is due to the adequate data on fuel consumption only derived from PT. PERTAMINA, excluding the sales data from foreign fuel companies and CNG stations. According to Suhadi(9), the actual estimation by using this approach considered exceeds the calculation if the data does not include the entire fuel consumption from road-based transportation. Also, the CNG-fueled vehicles have been introduced in Jakarta since the 2010s. Table 2 below shows the estimation of CO_2 emission from the energy consumption of road-based transportation in Jakarta in 2015.

Table 2: Estimation of CO_2 Emission from the Energy Consumption of Road-Based Transport in Jakarta in 2015

No.	Fuel	Energy Consumption (TJ)	CO_2 Emission Factor (kg/TJ)	CO_2 Emission (Million Tons)
1	Gasoline	688,117	69,300	47.7
2	Diesel	26,272.35	74,100	1.9
		Total		49.6

Source: Analysis, 2017.
Notes: Excluding the data from foreign fuel companies and CNG stations

Another estimation of traffic-related CO_2 emission can also be tracked by average vehicle kilometre travelled inside the highway and BRT lanes. This is due to statistic data that recorded frequently. Although it is not cover the entire VKT in the city, this figure can reflect at least the CO_2 emissions inside the highways and BRT lanes. Until 2015, the road length of highway in Jakarta reached 139 km (2% of the total road length) and the BRT lanes reached 240 km (4% of the total road length). The entire highway area only reached 3.2 km^2 (0.4% of the Jakarta's area).

Table 3 below shows the estimation of CO_2 emission in Jakarta's Highway in 2015. The number of vehicles is derived from the average vehicles per day in the highway. The author used the assumption that every single vehicle inside the highways mostly same day by day. This condition is due to the daily commuter pattern. The VKT per day multiply by 365 days resulting in VKT per year. On the other hand, the VKT per year for BRT lanes only multiply by 329 days as the remaining days are dedicated to bus service and maintenance. Fuel efficiency is derived from the standards from Ministry of Transportation.

Table 3: Estimation of CO_2 Emission In Jakarta's Highway and BRT Lanes In 2015

No.	Vehicles Fleet in Jakarta's Highway	Number of Vehicles	VKT per year per vehicles	Fuel Efficiency (litre/km)	CO_2 Emission Factor (gram/litre)	CO_2 Emission (Million Tons)
1.	Gasoline-Fueled	3,755,037	14,600	0.12	2003.4	13.2
2.	Diesel-Fueled (Trucks, Public Buses, etc.)	416,629	12,775	0.17	2220.4	2.0
No.	**Vehicles Fleet in BRT Lanes**	**Number of Vehicles**	**VKT per year per vehicles**	**Fuel Efficiency (litre/km)**	**CO_2 Emission Factor (gram/litre)**	**CO_2 Emission (Million Tons)**
1.	Diesel-Fueled BRT Coach	297	54,531	0.17	2220.4	0.01
2.	CNG-Fueled BRT Coach	205	54,531	0.8	0.00206	*
			Total			15.21

Source: Analysis, 2017.

** = 18.5 kg CO_2*

The estimation of CO_2 emission in Jakarta's highway and BRT lanes in 2015 reached 15.21 million tons. According to Suhadi[9], the actual estimate by using this approach and its limitation considered exceeds the calculation because PT. Jasa Marga did not distinguish between gasoline-fueled and diesel-fueled private vehicles. Both private vehicles are classified in Class 1, while other diesel-fueled vehicles are classified from Class 2-5. Thus, the recorded data to distinguish between gasoline-fueled and diesel-fueled private vehicles seemed hard to obtain in practice. In addition, this approach does not consider the traffic congestion/idling inside the highway and BRT lanes. In fact, the traffic congestion almost occurred every day inside the highway and the particular BRT lanes that have mixed-traffic with the regular road. Suhadi[9] mentioned the field CO_2 estimation of traffic congestion/idling need much effort and time because there is a need to have a continuous traffic congestion/idling data in many days, including the average speed and vehicle fleet/technology.

The different figure and number of both approaches indicate the data limitation and assumption. Because both methods come from the various data basis, the comparison among them seemed less coherent. But, Suhadi[9] emphasised that the accumulation of CO_2 emission in Jakarta's highway, BRT lanes, and non-highway would exceed the estimation of the top-down approach. This figure seemed hard to prove nowadays because there was inadequate data of vehicle kilometre travelled (VKT), especially the VKT for the non-highway segment and VKT for the motorcycle trips. This circumstance is due to the significant number of motorcycles in Jakarta's road daily as well as there was a difficulty in conducting a massive survey to count the traffic in non-highway and non-BRT lanes.

Suhadi[9] emphasised for the CO_2 estimation in the non-highway segment cannot rely also on the number of registered vehicles because most vehicles in Jakarta come from suburban and registries their vehicle in suburban. The static traffic data would not reflect this circumstance. Most vehicles in Jakarta come from suburban. They refuel the gasoline in the suburban area, which is not accounted in the Jakarta's gasoline sales. But, they do the daily commuter pattern to Jakarta and emit CO_2 emission in Jakarta's area.

The author also conducted comparative studies with Beijing and New Delhi in this particular topic. The lesson learned suggests Jakarta must become more stringent in controlling the traffic-related CO_2 emission, like in Beijing and New Delhi. First, Jakarta Municipality must implement the vehicle emission standards into at least Euro 4. Secondly, Jakarta Municipality should record an adequate data on vehicle kilometre travelled (VKT) inside the city to precisely estimate the traffic-related CO_2 emission. Thirdly, the critical air pollution in Jakarta is more than Beijing and New Delhi. Jakarta, Beijing and New Delhi deal with the particulate concentration as significant air pollution from urban transport system. Meanwhile, Jakarta should manage its vehicle exhaust emissions to reduce NO_2 concentration. This substance is derived from inefficient gasoline combustion inside the vehicles. The accumulation of NO_2 in ambient air induced the existence of O_3. Table 4 below shows the comparison of specific variables of traffic-related CO_2 emission in Jakarta, Beijing, and New Delhi.

Aggarwal and Jain(10) mentioned China and India have considerable potential in managing motorised vehicles by implementing various technology and policy instruments. 'This circumstance is due to they have entered motorisation phase recently in comparison with other developing countries' (10). As mentioned in chapter 4, Indonesia was seen as a geographically strategic base for car manufacturing by Japanese automakers since after Japan's colonialized era in 1945s. Although the car is manufactured in Indonesia, the vehicle chassis and technology is still assembled in Japan. On the other, China and India have their own vehicle identities. Indonesia again became the consumer of private vehicles. Jakarta has the most significant amount of registered population vehicles among the three cities, reached 18 million vehicles in 2015.

Various methods in estimating traffic-related CO_2 emission become reliable when it is confronted with the adequate data. Then, the chosen method represented the perspective, advantages, weaknesses, and the limitation of CO_2 emission estimation. Various methods had been used to calculate the traffic-related CO_2 emission in many cities in Indonesia. Most of the big cities in Indonesia, including Jakarta, use the top-down approach, while the rest use the middle approach through the calculation of traffic flow. Suhadi(9) emphasised due to the most common top-down approach (gasoline consumption as a data basis), the traffic-related CO_2 emission is considered as a part of energy emission in national inventory. It reflected on the Regulation of the Minister of Environment No. 12 Year 2010 on the Implementation of Air Pollution Control in the Local Region. Suhadi(9) asserted this merging inventory between transportation and energy sector is somewhat lead to the aggregate condition and makes the CO_2 estimation does not precise in practice.

Table 4: The Comparison on Certain Variables of Traffic-Related CO_2 Emission In Jakarta, Beijing, and New Delhi

No.	Variables	Jakarta	Beijing	New Delhi
1	Administrative Area	661.5 km^2	16,808 km^2	42.7 km^2
2	Urban Area	6,943 km^2	4,144 km^2	51,109 km^2
3	Registered Population in 2015	10.23 million inhabitants	21.5 million inhabitants	21.75 million inhabitants
4	Registered Vehicle Population in 2015	18 million vehicles	5.5 million vehicles	8.3 million vehicles
5	Urban Transport System	BRT, Commuter Train, and Public Bus	BRT, Train, Metro, Subway, and Public Bus	BRT, Train, Metro, Subway, and Public Bus
6	CO_2 Estimation from Road-Based Transportation in 2005	16.91 Million Tons	23 Million Tons*	35 Million Tons**
7	Adequate VKT Data	No	Yes	Yes
8	Common Method in Estimating CO_2 Estimation from Urban Transport	Top-Down Approach (Gasoline Combustion)	Top-Down Approach (Gasoline Combustion), Middle Approach (Traffic Flow), and Bottom-Up Approach (VKT)	Top-Down Approach (Gasoline Combustion), Middle Approach (Traffic Flow), and Bottom-Up Approach (VKT)

No.	Variables	Jakarta	Beijing	New Delhi
9	Vehicle Emission Standard	Euro 2, few vehiles use Euro 3 or 4	China 4 (equivalent to Euro 4)	Bharat IV (equivalent to Euro 4)
10	CO_2 Emission Factor	Average (National)	Specific (Local)	Specific (Local)
11	Motorcycle Banning	In Primary Road	Within radius of 300km^2 from the city centre	None
12	Critical Air Pollutants from Urban Transport System	PM_{10}, NO_2, and O_3	Particulate Concentration ($PM_{2.5}$ and PM_{10})	Particulate Concentration ($PM_{2.5}$ and PM_{10})

Source: Analysis, 2017.
**: Wang, et al., 2010*
***: Reddy and Balachandra, 2014.*

To develop precise method on traffic-related CO_2 emission, the VKT information is urgently needed. This data along with the vehicle fleet and correct CO_2 emission factor into the model can bring the estimation of traffic-related CO_2 emission one step further as needed by fast-growing economy countries, such as India, Indonesia, and China. Meanwhile, Wang, *et al.*(12) emphasised the vehicle emission are challenging to simulate because it relies on many factors and varies both time and spatial significantly. The figure below shows the framework of the bottom-up approach, using VKT as a primary data basis.

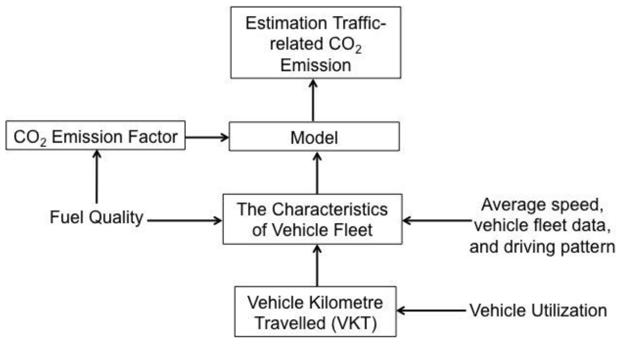

Figure 1: The Framework of Bottom-Up Approach in Traffic-related CO_2 Emission

Source: Analysis, 2017.

4. CONCLUSION

This research tries to provide a brief explanation of traffic-related CO_2 emission in Jakarta. The urban transport system in Jakarta contributed the highest rank on city's CO_2 emission inventory. This sector emitted a portion of 45% with the amount of 19.61 MtonCo$_2$eq in 2005. In 2005, the method of mobile combustion was used for the calculation of traffic-related CO_2 emission in Jakarta(15). This condition is due to the only available and accurate input is the data that provided by Oil and Gas State-Owned Company, PT. PERTAMINA. According to Jakarta Municipality, the traffic-related CO_2 emission will reach 87.39 million ton Co$_2$ in 2030 by using the 2005's base year.

Using the same method in 2015, the traffic-related CO_2 emission increased 270% and reached almost 50 million tons CO_2. This circumstance is due to the increased fuel consumption. On the contrary, this approach seemed not just as single step calculation as in 2005. This condition is due to the adequate data on fuel consumption only derived from PT. PERTAMINA, excluding the data from foreign fuel companies and CNG stations, as they entered the gasoline market in Jakarta after 2005. According to Suhadi(9), the actual estimation by using this approach considered exceeds the calculation if the data does not include the entire gasoline consumption.

Various methods for estimating traffic-related CO_2 emission become reliable when it is confronted with the adequate data basis. Then, the chosen method represented the perspective, advantages, weaknesses, and the limitation of CO_2 emission estimation. At the same time, there are inadequate data regarding the entire vehicle kilometre travelled (VKT) in Jakarta. The whole VKT data is urgently needed to develop precise method on traffic-related CO_2 emission.

Currently, the adequate VKT data covers only inside the highways and BRT lanes. This figure only covers 6% of the total road length in Jakarta Then, this thesis tries to estimate that the 379 km roads in Jakarta, consisting of 139 km of highway and 240 km of BRT lanes. According to PT. Jasa Marga(13), the average vehicle kilometre travelled inside the highways reached 40 km/day for private vehicles and 35 km/day for diesel-driven vehicles (bus and truck). ITDP Indonesia(7) mentioned the average VKT for BRT coaches reached 166 km/day/bus. By using this data, the estimation of CO_2 emission in Jakarta's highway and BRT lanes in 2015 reached 15.21 million tons. This number reaches 30% from the top-down approach estimation. However, it is only an integral part of the whole CO_2 emission inventory form road-based transportation. It's excluding CO_2 emission from all motorcycles trip and non-highway traffic.

On the other hand, since there is an inadequate data on VKT on other roads, it is challenging to measure the remaining amount of other roads emission. The road status and traffic activity must also take into consideration to this condition. The bottom-up approach in estimating CO_2 that sum up the disaggregation estimation data from each road can lead into develop precise method on traffic-related CO_2 emission.

In answer to the Jakarta's effort to reduce the traffic-related CO_2 emission based, the national government is lagging behind China and India in implementing the vehicle emission standards. Currently, Indonesia has applied Euro 2 standard, while China and India have performed equally to Euro 4 standard. The other efforts range from vehicle emission test, the use of low emission gasoline (CNG), traffic restraint, car-free day program, and public transport development and improvement. The scholars are still discussing the effectiveness of these efforts. The governance of those strategies is scattered in term of defining the reliable method on measuring traffic-related CO_2 emission. The reliable method of traffic-related CO_2 emission in Jakarta seemed continuously utilise the top-down approach although this technique does not provide precise estimates of the traffic-related CO_2 emission in practice.

From the view of developing precise method on traffic-related CO_2 emission, this thesis presents a various methods to estimate vehicle emission. Because the methods derive from various data, the comparison among them seemed less coherent. But, one method can validate and describe what the limitation of other methods. The traffic-related CO_2 estimation in highway and BRT lanes reached 30% from the top-down approach. However, this static emission inventory is not completely identical to the actual emission in the cities. This circumstance is due to the complexity of vehicle activities and data recorded in practice.

Therefore, this thesis revealed that the traffic-related to CO_2 emission in Jakarta, Indonesia has weaknesses in term of the method and the emission control. Beijing and New Delhi are in the forefront in term of VKT data, while Jakarta still utilise the gasoline consumption data (top-down approach). Beijing is the most stringent city in controlling the emission control among the three cities.

FURTHER RESEARCH POSSIBILITIES

a. The most challenging data for this topic is defining the vehicle kilometre travelled (VKT). For future research, the study on VKT within Jakarta's area must be gained.
b. This thesis only addresses the CO_2 estimation from road-based transport modes as a part of the urban transport system. This thesis did not consider the CO_2 emission that generated by commuter line train and soon by MRT and LRT. This condition is due to these modes used electricity as primary power. For future research, the study on CO_2 emission from rail-based transport modes can complement the research on traffic-related CO_2 emission from road-based transport.
c. This thesis only addresses the CO_2 estimation from road-based transport modes by linear pattern calculation. The analysis does not include specific modelling or simulation. For in-depth research, the use of modelling software can be conducted.

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