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Urban Air Pollutant from Motor Vehicle Emissions in Kuala Lumpur, Malaysia

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ABSTRACT

The increasing amount of motor vehicles that emit pollutants are contributing significantly to urban air pollution, be it in industrial or developing countries. This study investigates the emission of particulate matter (PM_{10}) from exhaust and non-exhaust sources and gaseous pollutants, such as carbon monoxide (CO) and nitrogen oxide (NO_x) from several different classes of motor vehicles in the tropical city of Kuala Lumpur. Air pollutants from fuel consumption were obtained from emission factors, while non-exhaust particulate matter was estimated from the United States Environmental Protection Agency (U.S. EPA) Compilation of Air Pollutant Emissions Factors (AP-42). The total PM_{10} emissions from all classes of motor vehicles estimated from the tail-pipe exhaust was 1,029,883 kg, while non-exhaust sources were 1,573,539 kg. Emissions of PM_{10} from newly registered private cars was the most dominant at 214,427 kg, followed by emissions from motorcycles at 118,582 kg in 2014. Private cars also contributed 14,605 kg of CO and 5,726 kg of NO_x in 2014, compared with 9,830 kg of CO and 3,854 kg of NO_x in 2010. Comparison with other Organisation for Economic Co-operation and Development (OECD) countries shows that the total emissions for PM_{10} and NO_x were lower in Malaysia than in most countries, but the CO emissions here were higher than in Asian countries such as Japan and Korea, as well as in other European countries. Various strategies and policies should be implemented by the local authorities and government agencies to reduce emissions from the transportation sector in urban areas to improve the quality of the urban environment, human health, and the urban community.

Keywords: Urban traffic; Gaseous emissions; Private cars; Urban pollution; Asia Pacific.

INTRODUCTION

The transportation sector is a major source of traffic pollution in the city center. High levels of economic growth, rapid urbanization, increasing disposable income, a variety of social and recreational activities, increasing private vehicles, and the distribution of dissimilar materials and resources have directly increased the demand for the transport sector and leading to a deteriorating urban air quality (Saboori *et al.*, 2014; Shahbaz *et al.*, 2015). These increasing emissions from the transportation sector are contributing factors to domestic air pollution, global climate change, human health problems, and ground-level ozone formation at both regional and national scales (Saija and Romano, 2002; Azam *et al.*, 2016).

Epidemiological evidence has identified traffic pollution as a risk factor for adverse health outcomes, including respiratory disease incidences (Zhu *et al.*, 2012; Laumbach and Kipen, 2014), cardiovascular diseases (Jerrett *et al.*, 2013; Beelen *et al.*, 2014; Su *et al.*, 2019; Wei *et al.*, 2019), and premature mortality (Su *et al.*, 2015). Thus, WHO estimates approximately 4.2 million premature death cases worldwide (WHO, 2018). Recently, a relationship between traffic pollution and other diseases such as cognition, mental health and dementia, and air pollution has been identified (Luyten *et al.*, 2018; Shehab and Pope, 2019; Hu *et al.*, 2020).

Generally, the major sources of urban air pollution to individual health are particulate matter (PM) and nitrogen dioxide (NO_2) through emission from vehicle exhaust (Ghaffarpasand *et al.*, 2020). In 2016, on-road vehicles accounted for about 39% and 20% of total NO_x and carbon monoxide (CO) emissions in the European Union (EU), and it is found those passenger vehicles are the major cause of NOx and CO emissions from road transportation (EEA, 2018). Meanwhile, motor vehicles using diesel fuel have been identified as a major contributor to high NO_x emissions in Europe (Anttila *et al.*, 2011; Henschel *et al.*, 2015) beside CO and total hydrocarbons (THC) (Yang *et al.*, 2020).

Fuel Consumption and Motor Vehicle Emissions

The transportation sector consumes about 48 million barrels of oil per day compared to the current global total of

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93 million barrels of oil a day from more than 1.5 billion motor vehicles (EIA, 2014). Fuel consumption is defined as the amount of fuel consumed per unit distance and expressed in litres/100 km. The lower value of fuel consumption by vehicles has shown that high savings occur (Mathew, 2014). The higher octane petrol is cooler and significantly produces lower nitrogen oxide (NO_x) release levels (Al-Arkawazi, 2019).

Cheah *et al.* (2008) investigated that fuel consumption and emission of pollutants from motor vehicles recorded a reduction from 11.2 litres/100 kilometres in 2007 to 5.6 litres/100 km, while the sales-weighted average fuel economy increased from 21 miles per gallon (mpg) in 2007 to 42 mpg by 2035. The International Energy Agency (IEA) specified that energy consumption from the global transport sector and greenhouse gas emissions are expected to increase by approximately 50% by 2030 and 80% by 2050 (Huang *et al.*, 2020). Higher fuel consumption in motor vehicles was detected at urban signalised intersections due to the frequent changing of vehicle modes of deceleration, acceleration, and stopping (Wu *et al.*, 2020).

In Malaysia, private cars, motorcycles, light, and heavy vehicles are major contributors to deterioration in air quality, especially in urban areas. The total number of newly registered motor vehicles from 2004 to 2017 was 286,771,902 units, comprising five classes: passenger cars, motorcycles, vans/lorries, and taxis/buses (DOE, 2017). Motorcycles and passenger cars are the dominant classes of motor vehicles, with 6,572,366 units in 2004 that increased by 35% to 11,989,591 units in 2015 (DOE, 2015). The same situation was shown for passenger cars, with 5,911,752 units in 2004 that grew by 35% to 13,173,030 units in 2017 (DOE, 2015, 2017).

Motor vehicles and traffic emissions are directly related to the fuel consumption caused by an incomplete combustion process in the engine system. Fuel consumption from the transport sector in Malaysia showed an upward annual trend, as evidence by the 5,386 kilotonnes of oil equivalent (ktoe) in 1998 that rapidly increased to 23,435 ktoe in 2015 (Energy Commission Malaysia, 2014). Combustion of fossil fuels from petrol, fuel oil, and natural gas in the internal combustion engine of a motor vehicle releases air pollutants, such as carbon monoxide (CO), sulphur dioxide (SO_2), oxides of nitrogen (NO_x), non-methane volatile organic compounds (NMVOC), and particulate matter (PM) (Ong *et al.*, 2011; Azam *et al.*, 2016). In addition, transport activities from private and goods vehicles emit about 20% of greenhouse gases (World Bank, 2014; Alshehrya and Belloumi, 2017).

In Malaysia, energy consumption directly relates to the transport sector, foreign direct investment, and pollutant emissions that resulted from positive economic growth (Department of Statistics Malaysia, 2011). Consequently, higher fossil fuel consumption in Malaysia resulted in a 6.7% increase in annual average growth from the transportation sector from 1971 to 2008, which is comparable to Thailand at 6.6% and Indonesia at 6.3% (Ghosh, 2010). The increased consumption of fossil fuels in Malaysia from 1960 to 2002 resulted from the increasing motor vehicle ownership, with an average of 6.7% for 1,000 persons (Dargay *et al.*, 2007). The energy use from the transportation sector from fossil fuels was estimated at 50% in Malaysia, which is the highest in ASEAN (Chandran and Foon, 2013). Traffic emissions are also influenced by rapid urbanisation that impacts the population, economic growth, and activity services, particularly in the city centres. According to the 10th Malaysia Plan, the rate of urbanisation in Malaysia has increased from 25% in 1960 to 65% in 2005, with the expected increase of 75% of the population residing in the Klang Valley conurbation by 2020 (Kuala Lumpur City Hall, 2004).

Thus, the objective of this study is to calculate the emissions of particulate matter from the exhaust and non-exhaust and gaseous pollutants from the fuel consumption of the vehicle class passenger cars, motorcycles, buses, and goods transport from 2010 to 2014 in the metropolitan city of Kuala Lumpur. This study utilizes the top-down approach based on fuel consumption for CO and NO_x, and the bottom-up approach (vehicle kilometre travelled (VKT) and number of vehicles) for particulates. The CO and NOx emissions from motor vehicle exhausts are calculated based on fuel consumption (Masjuki *et al.*, 2004; Kakouei *et al.*, 2012), while the particulates include the exhaust PM_{10} and non-exhaust source from paved roads. The different approach for CO and NO_x are used, as they are gaseous pollutants from motor vehicles through the fuel combustion process as petrol and diesel directly affect the levels of CO and NO_x released. For PM_{10} emissions from motor vehicle exhaust, it is estimated using VKT and number of vehicles (EIA, 2005) because the movement the motor vehicles or driving patterns directly influence the emission of PM_{10} (Rostampour, 2010). Thus, VKT is affected by the flow of traffic and traffic congestion. Furthermore, the number of vehicles also caused serious traffic congestion through different driving patterns. The CO, NO_x, and PM_{10} emissions will be compared to the Organisation for Economic Co-operation and Development (OECD) countries to gauge the rank of an environmental indicator of urban Kuala Lumpur that represents a developing country. The identification of the vehicle class that contributes the most emissions to the atmosphere in Kuala Lumpur may help policymakers to adopt a strategy to reduce air pollutants and the impacts of climate change on the city.

MATERIALS AND METHOD

Study Area: Urban Kuala Lumpur

Kuala Lumpur (KL) is the federal capital of Malaysia and is a prominent and sophisticated city in Southeast Asia, acting as a centre of commercial and industrial activities (Ling *et al.*, 2010; Teriman *et al.*, 2010; Jamhari *et al.*, 2014). Kuala Lumpur covers an area of 24,221 hectares and is located on the west coast of Peninsular Malaysia (Fig. 1). It has a total population of 1,627,172 inhabitants and a density of over 6,800 persons per square kilometre (Teriman *et al.*, 2010). More than 60% of Malaysians live in urban areas in 2010 and it is predicted to increase to 75% in 2020 (Shuid, 2004).

Kuala Lumpur city is situated in the Klang Valley or Kuala Lumpur Conurbation (KLC). Under the Kuala Lumpur

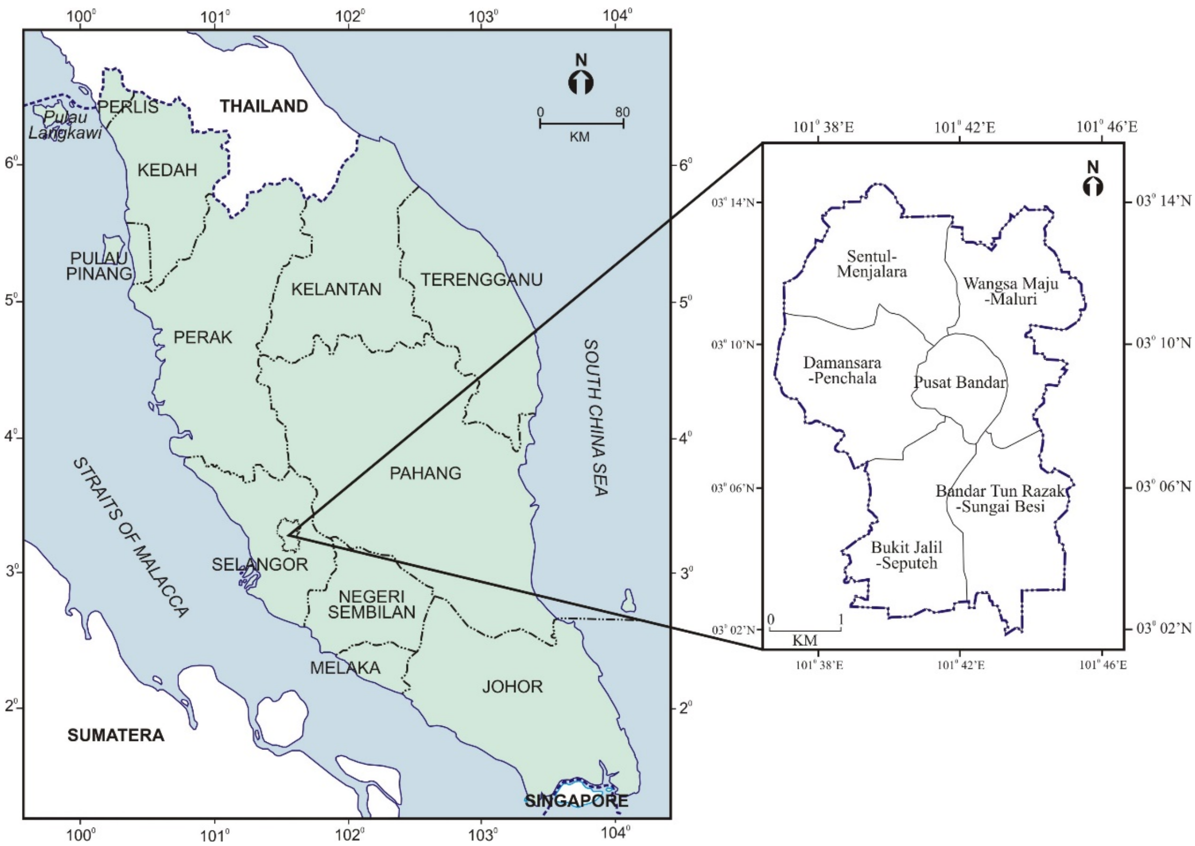

Fig. 1. Map of six strategic zones in Kuala Lumpur.

Structure Plan (2004–2020) and the Kuala Lumpur City Plan, it was divided into six strategic planning zones for the purposes of city planning (Architects and Urban Planners Malaysia, 2006) consisting the City Centre, Sentul–Menjalara, Wangsa Maju–Maluri, Damansara–Penchala, Bukit Jalil–Seputeh, and Bandar Tun Razak–Sungai Besi (Ling *et al.*, 2012). Road transport represents 84% of the city's mobility, with private cars accounting for 57% of all motorised trips in Kuala Lumpur (Kuala Lumpur City Hall, 2004). Currently, Kuala Lumpur has a total of 1,213 kilometres of road length (Teriman *et al.*, 2010). According to a report from the Public Work Department of Malaysia (2014), the overall road network in Kuala Lumpur, covering Kuala Lumpur–Kuala Selangor, Kuala Lumpur–Ipoh, Kuala Lumpur–Seremban Expressway, and Kuala Lumpur–Damansara, with a total length of 1,531.20 km, had a traffic volume recorded at 1,083,320 units for a 16-hour duration in 2010.

Newly annual registered motor vehicle data for Kuala Lumpur was provided by the Department of Road Transport Malaysia (MOT) at the Wangsa Maju branch. Data were classified to different categories and according to the fuel consumption of private cars and motorcycles (petrol), and buses and goods vehicles using diesel from the year 2010 to 2014. The exhaust emissions of CO and NO_x are obtained from their fuel consumption, while particulate matter emission is estimated based on Baidya and Borken-Kleefeld (2009). The non-exhaust particulate matter from paved roads is calculated using the formula from the emission factors provided by the United States Environmental Protection Agency (U.S. EPA) AP-42 (U.S. EPA, 2011).

Fuel Consumption

Fuel consumption for each vehicle class was analysed using Eq. (1) below by Kakouei *et al.* (2012):

$$F_c = A_c \times V \times R_d \quad (1)$$

where:
F_c = Fuel consumption in a day (diesel or petrol) in litres;
A_c = Average fuel consumption by each type of vehicle per kilometre (L km^{-1});
V = Number of each type of vehicle; and
R_d = Amount of running per day by the vehicle (km).
* The value of Rd is the number of vehicle trips (km) per day and is estimated from the survey answered from 200 residents in Kuala Lumpur (Mohd Shafie, 2019). The small value of Rd is because it involves the average short-range distance performed by the residents of Kuala Lumpur. The average daily distance travelled is 14 km.

The emissions of CO and NO_x were next calculated from fuel consumption using Eq. (2) (Masjuki *et al.*, 2004):

$$TMi = CF\,(ES \times FE\ 1p + ES \times FE\ 2p + ES \times FE\ 3p + \ldots + ES \times FE\ np) \quad (2)$$

where:
TMi = Total emission in year i (kg);
ES = Energy use in year of fuel type (ktoe);

FE n/p = Emission per unit energy of fuel type n (kg GJ^{-1});
CF = Conversion factor.
* The conversion factor (CF) used in this study is 1 toe = 41.86 GJ (UN, 1991; IEA, 2002; EIA, 2004).
* Energy use of fuel type (ES) in ktoe is calculated from the total registration of motor vehicles by year with energy use values derived from Malaysia Energy Statistics Handbook reports from 2010 and 2014 (Malaysian Energy Commission, 2017). The emission per unit energy of fuel type is constant according to pollutants for petrol and diesel as shown in Tables 1 and 2.

Therefore, this study only estimated emissions from private cars using petrol and not diesel. Data from the Department of Road Transport Malaysia (MOT) showed that the total number of private cars using petrol is 10,906,065 units (62.37%) compared to 148,207 units of diesel cars (0.84%) from 2010 to 2014.

Particulate Matter Emissions

Particulate matter emissions from road vehicles comprise emissions from tailpipe exhaust and non-exhaust emissions such as brake, tires and clutch, and re-suspension of dust (Thorpe and Harrison, 2008). Particulate emissions from the surface of paved roads via the movement of motor vehicles are estimated by using the following equation from U.S. EPA AP-42 (U.S. EPA, 2011). Default values used in this analysis: k = 4.6, sL= 0.62 g m^{-2}, W = 3.4 tonnes (U.S. EPA, 2011).

$$E = k\,(sL)^{0.91} \times (W)^{1.02} \quad (3)$$

where:
E = Particulate emission factor (units match the units of k);
k = Particle size multiplier for particle size range and units of interest;
sL = Road surface silt loading (grams per square meter) (g m^{-2}); and
W = Average weight (tonnes) of vehicles traveling the road.

Meanwhile, particulate matter emission from vehicle exhaust is based on mainly the fuel consumption (petrol and diesel), vehicle kilometre travelled (VKT), and emission factors. VKT is derived from Eq. (4) (EIA, 2005) and emission factor using Eq. (5).

$$\text{VKT} = \text{Number of vehicles x Distance travelled} \quad (4)$$

$$E_P = \sum (N \times VKT \times e) \quad (5)$$

where,
E_P = Total emissions E of a pollutant p;
N = Number of vehicles (unit);
VKT = Average annual vehicle kilometer travelled (km);
e = Emission factor.

Emission factors for private cars and motorcycles (petrol) are obtained from Baidya and Borken-Kleefeld (2009) while buses and goods vehicle are based on Euro 4 emission limits for RON95 and RON97 in Malaysia (Table 3).

RESULTS AND DISCUSSION

Motor Vehicles in Kuala Lumpur

The total number of new motor vehicles registered from 2010 to 2014 consists of private cars, motorcycles, goods vehicles, and buses. The annual trend showed a continuous increase of 3.71% per year from 3,161,741 units in 2010 to 3,812,460 units in 2014 (Fig. 2). The highest numbers of vehicle classes are the private cars and motorcycles, which recorded 10,906,065 units (an increase of 62.37%) in 2014 and 6,030,752 units in 2010. This is in contrast to a lower number of goods vehicle at 498,837 units or 2.85% increase, while buses showed a lower quantity of 48,113 units or 0.27% of the total vehicles.

The total newly registration motor vehicles in Kuala Lumpur significantly showed annual averaged VKT for private cars is highest year by year from 26,259,715 km in 2010 to 31,919,321 km in 2014 compared to other vehicles classes. In addition, motorcycles recorded an increasing annual averaged VKT of 14,658,117 km and reached 17,651,935 km beside 1,307,720 km to 1,371,397 km for goods transport during the study period (Table 4).

The total pollutants emitted by private cars, motorcycles, buses, and goods vehicles from 2010 to 2014 for PM_{10} (exhaust and non-exhaust), CO, and NO_x are 2,603,422 kg, 80,875 kg, and 33,437 kg, respectively (Fig. 1). The total PM_{10} emissions from exhaust is 1,029,883 kg and 1,573,539 kg from non-exhaust from 2010 to 2014. Overall, non-exhaust PM_{10} emissions from private cars and motorcycles emit the highest total of PM_{10} in 2014 at 214,427 kg and 118,582 kg, respectively. This is followed by tailpipe PM_{10} emission of 142,952 kg from private cars and 79,055 kg by motorcycles in 2014. Meanwhile, goods vehicles released 9,212 kg of PM_{10} in 2014. Buses also showed similar conditions but in minimal quantities from 864 kg in 2010 to 869 kg in 2014.

Transport Emissions in Kuala Lumpur

The CO emission from private cars was high, which was about 14,605 kg in 2014 in contrast to 9,830 kg in 2010. Additionally, goods vehicles and buses produced CO emissions of 72 kg and 69 kg in 2010, respectively, from which the numbers had slightly increased to 79 kg and 70 kg, respectively, in 2014. Similarly, NO_x also accounted for the

Table 1. Energy use for fuel type and motor vehicle (ES) in ktoe.

Motor vehicle	2010	2011	2012	2013	2014
Motorcycles (petrol)	9560	8155	10843	12656	12705
Private cars (petrol)	9560	8155	10843	12656	12705
Buses (diesel)	8388	8712	9410	9568	10161
Goods transport (diesel)	8388	8712	9410	9568	10161

Source: Malaysian Energy Commission, 2017.

Table 2. Emission per unit energy of fuel type for petrol and diesel (FE) (kg GJ^{-1}).

Fuel Type	Emission	
	CO	NO_x
Petrol	3.490	1.368
Diesel	0.102	0.284

Table 3. Emission factor for PM_{10} emission from exhaust according to fuel type and motor vehicles classes.

Motor vehicle class	EF (g km^{-1})
Private cars (petrol)	0.06
Motorcycles (petrol)	0.06
Buses (diesel)	0.025
Goods vehicle (diesel)	0.025

high emission from private cars and motorcycles with 5,726 kg and 1,750 kg compared with 3,854 kg and 1,200 kg, respectively, from 2010 to 2014 (Table 5).

The highest PM_{10} emissions in Kuala Lumpur were from private cars and motorcycles during peak hours at 0700 to 0900 and at around 1700 hr to 2000 hr in the morning and evening, respectively (Azhari *et al.*, 2018). This significantly increased the emissions due to the minimum speed limits of the vehicles and stop-and-go vehicle in traffic lights (Madireddy *et al.*, 2011). Individual attitude and driving patterns, characteristics and types of vehicles, the physical aspect of road surface, average vehicle speed, as well as traffic conditions all affect the rate of emissions (Barth and Boriboonsomsin, 2009).

Generally, CO and NO_x pollutants are emitted from fuel consumption in vehicle movement process, with diesel fuel producing higher emissions than petrol. However, the emission from petrol fuel is also attributed by the high number of motor vehicles compared with goods vehicles that consume diesel in Kuala Lumpur. Vehicles of less than five years with newer engine technology can reduce CO and NO_x emissions by 71% and 10%, respectively (Clark *et al.*, 2002).

Taxi was excluded in this study, where it cumulatively accounted for only 335 units in 2010, which increased to 336 units in 2014, through the use of natural gas (natural gas vehicles or NGV) in Kuala Lumpur. Furthermore, the rapid growth of mobile technology and smartphone applications significantly led various companies to develop relationships with consumers through mobile applications (Zhang, 2017; Chin and Lai, 2018). For example, MyTeksi was introduced in Kuala Lumpur and was subsequently branded as GrabTaxi in 2011. Then, GrabCar was officially launched in Malaysia following the increasing use of GrabCar due to usage of safety, time efficiency, and convenience to passengers and drivers alike in 2014 (Jayaraj *et al.*, 2019).

In Malaysia, Grab was launched in 2012 as a third-party taxi e-hailing mobile application (Lin and Dula, 2016). Report from The Land Public Transport Commission (SPAD) summarized that 80% of the public are more likely to use Uber and GrabCar services due to high accessibility factors (New Straits Times, 2017). Today, Grab is the best platform for driving individual day trips mostly for drivers and passengers to choose and use the Grab application in Southeast Asia. Therefore, using taxis for mobility is deemed impractical and not the popular choice for Kuala Lumpur residents.

The Organisation for Economic Co-operation and Development (OECD, 2019) also released information on the road transport emissions of CO, NO_x, and PM_{10} (Table 6). The list of countries included for comparison are Germany, which represents an industrialised European nation; Chile and New Zealand, which represent the countries in the Southern Hemisphere; while Japan and Korea represent the Asian Pacific countries. No information is available for ASEAN countries. Germany recorded the high emissions of PM_{10}, NO_x, and CO in 2010 but displayed a decreasing trend in 2014. Asian countries, such as Korea, also showed a similar

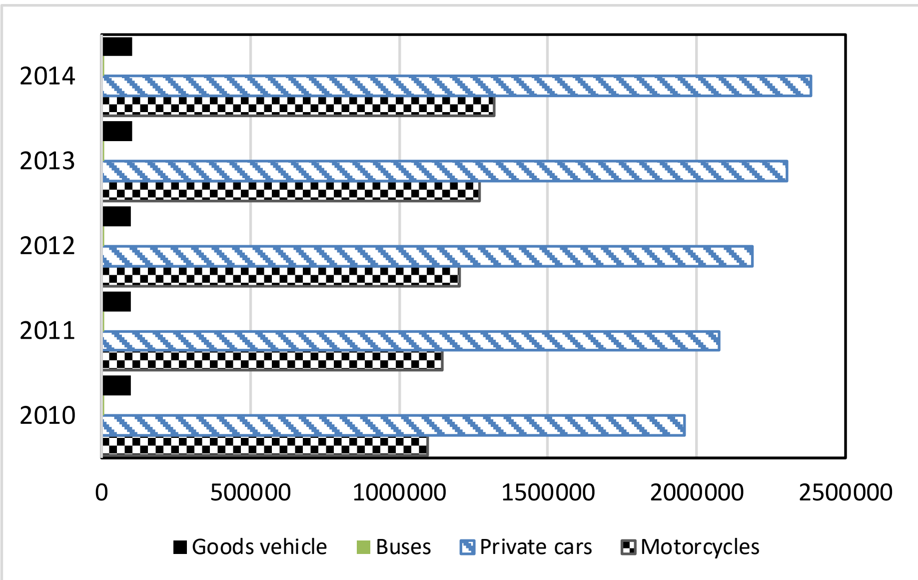

Fig. 2. Annual total ownership registration of motor vehicles in Kuala Lumpur (2010–2014).

Table 4. Annual vehicle kilometer travelled (VKT) in Kuala Lumpur (2010–2014).

Vehicle Class	Total vehicle registered (unit)	Averaged annual VKT (km)
2010		
Motorcycles	1,094,113	14,658,117
Private cars	1,960,081	26,259,715
Buses	9,601	1,286,27
Goods vehicle	97,611	1,307,720
2011		
Motorcycles	1,143,270	15,316,686
Private cars	2,0736,15	27,780,760
Buses	9,611	128,761
Goods vehicle	98,505	1,319,697
2012		
Motorcycles	1,204,920	16,142,627
Private cars	2188458	29,319,341
Buses	9616	128,828
Goods vehicle	99467	1,332,585
2013		
Motorcycles	1,270,871	17,026,190
Private cars	2,301,385	30,832,254
Buses	9,629	129,002
Goods vehicle	100,890	1,351,650
2014		
Motorcycles	1,317,578	17,651,935
Private cars	2,382,526	31,919,321
Buses	9,656	129,364
Goods vehicle	102,364	1,371,397

Table 5. Gaseous and PM_{10} emissions (kg) from new registered vehicles in Kuala Lumpur (2010–2014).

Pollutant	Class/Years	2010	2011	2012	2013	2014
PM_{10} (exhaust)	Private cars	117605	124417	131307	138083	142952
	Motorcycles	65647	68596	72295	76252	79055
	Buses	240	240	240	241	241
	Goods vehicle	2440	2463	2487	2522	2559
	Total	**185932**	**195716**	**206330**	**217098**	**224807**
PM_{10} (non-exhaust)	Private cars	176407	186625	196961	207125	214427
	Motorcycles	98470	102894	108443	114378	118582
	Buses	864	865	865	867	869
	Goods vehicle	8785	8865	8952	9080	9213
	Total	**284527**	**299250**	**315221**	**331450**	**343091**
CO	Private cars	9830	11003	12323	13628	14606
	Motorcycles	3061	3344	3735	4154	4465
	Buses	70	69	70	70	71
	Goods vehicle	72	73	75	77	79
	Total	**13034**	**14490**	**16203**	**17930**	**19220**
NO_x	Private cars	3854	4314	4832	5344	5727
	Motorcycles	1200	1311	1465	1629	1751
	Buses	193	191	194	194	195
	Goods vehicle	200	203	207	213	220
	Total	**5448**	**6020**	**6698**	**7380**	**7893**

trend, where the CO and NO_x emissions in 2010 had further reduced to 409.218 thousand tonnes and 335.721 thousand tonnes in 2014, respectively. Improved green technology can be attributed to the declining trend of emissions.

For Malaysia, the emission data obtained from the Department of Environment had shown a significantly lower number compared with other OECD countries for PM_{10}, while the annual newly registered vehicles in Kuala Lumpur represent approximately 6% of the emissions. The increasing trend is small compared with other OECD nations. As a developing country, Malaysia displayed higher CO emissions from the transport sector at 1,597 tonnes in

Table 6. Comparison of road transport emissions (thousand tonnes) in Malaysia and selected OEDC countries (2010–2014).

Pollutant	Year	Germany	Canada	Iceland	Chile	Japan	Korea	New Zealand	Malaysia	Kuala Lumpur
PM_{10}	2010	34.41	33.88	0.19	1.88	NA	15.26	NA	4.49	0.003
	2011	33.47	32.90	0.17	1.86	NA	13.03	NA	4.44	0.003
	2012	31.95	31.80	0.17	1.77	NA	12.97	NA	4.59	0.003
	2013	31.07	31.49	0.16	2.26	NA	12.10	NA	4.34	0.003
	2014	30.30	30.06	0.15	2.54	NA	10.02	NA	4.27	0.003
NO_x	2010	537.08	562.68	3.00	61.19	397.55	368.05	69.38	213.79	0.005
	2011	523.16	550.22	2.58	65.40	410.90	382.23	71.41	216.43	0.006
	2012	506.13	529.67	2.40	66.76	371.21	322.31	72.33	226.21	0.007
	2013	495.61	492.88	2.34	75.58	339.06	345.67	72.35	220.79	0.007
	2014	493.12	469.02	2.37	80.37	313.92	335.72	73.69	223.05	0.008
CO	2010	971.93	2,318.37	9.43	305.69	618.92	583.72	519.98	1597.96	0.013
	2011	907.01	2,209.95	8.07	469.42	1,092.91	520.39	524.09	1671.00	0.014
	2012	884.37	2,011.03	7.21	480.02	944.54	463.54	516.13	1779.40	0.016
	2013	826.04	1,902.77	6.38	360.70	973.83	442.67	505.93	1786.40	0.018
	2014	805.88	1,860.25	5.93	285.03	843.51	409.22	503.89	1850.57	0.019

NA: Not available.

2010 and 1,850 tonnes in 2014 (DOE, 2011, 2015). The increasing trend of CO and NO_x emissions is mainly due to the increase in total motor vehicles, which mostly consume fossil fuel.

Malaysia should adopt more green transport initiatives since the trend of emissions of pollutants from the transportation sector in Malaysia is on the increase compared to other OEDC countries. Currently, approximately 90 percent of vehicles are fossil-fueled, hence the low number of environmental-friendly electric vehicles of less than 6,000 units on Malaysia roads (Md Khalili, 2019). China leads the market for electric vehicles with 2.3 million in 2018, followed by 1.3 million in Europe (IEA, 2019). In the US and Europe, mobile source emission controls such as exhaust after-treatment technologies for diesel and petrol vehicles that meet strict regulations have reduced emission (Winkler *et al.*, 2018). Stricter Euro 6 emission limits for petrol and diesel were imposed in Europe since 2015 (The Automobile Association, 2020). Policies in some OECD countries to reduce emissions include a zero-emissions vehicles (ZEVs) mandate in Canada by 2030, while in Korea initiatives include national subsidies for low-carbon vehicle purchases in 2018, abatement and subsidies on vehicle taxes, decreased road tolls and municipal parking rates (IEA, 2019).

Some of the reasons why the usage of electric cars is in low demand is due to the limited options of cars available, the expensive price tag of the cars from the tax of imported vehicles imposed by the Malaysia government, the lack of public awareness on the importance of green technology and environmental-friendly modes of transport (Bernama, 2019).

In order to achieve a green technology nation, the government needs to implement comprehensive initiatives to achieve these targets such as those outlined in the National Electric Mobility Blueprint (2015–2030) (GreenTech, 2015). By 2030, the government aspires to attain 100,000 electric cars; 100,000 electric motorcycles and 2,000 electric buses on Malaysian roads, as well as 125,000 charging stations (Bernama, 2019).

Malaysia should follow the industrialised OECD countries that had successfully reduced GHG and air pollutants from the road transport over the past ten years. Incentives for tax credits for those using green technologies, such as electric vehicles, should encourage more consumers to use affordable green vehicles that consume less fuel. The Malaysian Green Technology Corporation (MTDC) was charged to install 3,000 charging sites in government buildings, petrol stations, and shopping malls by 2018 to encourage for e-mobility of electric cars (Aswan, 2019), of which there were only 5,403 efficiency vehicle (EV) cars in March 2019. This is still below the target set by the National Electric Mobility Blueprint (2015) projection of 125,000 charging stations by 2030, where power supply for customers remains a problem (Zainuddin, 2019). Incentives were also given on energy efficiency vehicles (EEVI) and plug in hybrid efficiency vehicles (PHEV) as was implemented successfully in other Asian countries (China, Japan, India), Europe, and the USA. However, the growth of the EV industry in Malaysia is hampered by factors such as high price, slow infrastructure implementation, and technological limitation (Frost and Sullivan, 2019). Even the move by the Government of the United Kingdom to ban new sales of diesel vehicles by 2040 to achieve a sustainable, zero-carbon road transport system is considered too late by some (Shammut *et al.*, 2019).

EVs offer zero CO_2 tailpipe emissions and the highest energy efficiency compared to a fuel-based car that produced 152 g km^{-1}, a saving of 1.7 million tonnes of CO_2 (GreenTech, 2015). Among the positive impacts of electric vehicles (EV) are the decline in human toxicity exposure to ozone, and reduction in particulate matter formation which improves air quality as EV performs 8 times better than the Euro 6 diesel vehicles (Hooftman *et al.*, 2016).

It is estimated that a battery electric vehicle (BEV) produces lower NO_x emission of 36 mg km^{-1} (based on 2016 US electric grid) compared to Euro 6 petrol of 60 mg km^{-1}. Green vehicles will emit zero particulates and CO compared to the

0.3 mg km^{-1} emission of particulates and 500 mg km^{-1} of CO from the Euro 6 petrol (Winkler *et al.*, 2018). The emission reduction potential from the transportation sector would be beneficial to Malaysia environmentally when there is mass usage of EV as the air quality will be improved from zero emission of CO and particulate matter, and NO_x emission that will be halved.

Kuala Lumpur City Hall (KLCH) is a member of the C40 Cities Climate Leadership. Indeed, the issue of climate change has significantly encouraged the development of more intensive, practical, and integrated acts, policies, and strategies by policymakers and stakeholders in Malaysia. The Kuala Lumpur Low Carbon Society Blueprint 2030 was developed as its commitment to reduce emissions by 70% by 2022 against 2015 levels (Ho *et al.*, 2018). This amounts to a decrease in cumulative emissions of 134,345 tCO_2e and a financial saving in energy cost of RM76.1 million over this period of time. Some of the national policies in place include the national target of 40% emissions intensity reduction, Renewable Energy Act, National Green Technology Policy, National Energy Efficiency Plan, and National Policy on Climate Change. It has also committed to a target of 45% carbon intensity reduction by 2030 (relative to 2005 levels) (Kuala Lumpur City Hall, 2017).

In addition to the policies, the implementation of emission reduction focusing on the petrol quality of Euro in Malaysia would be impactful in reducing the amount of air pollutants emitted to the surrounding environment with the implementation of the two types of octane rating fuel for petrol in Malaysia, namely RON95 and RON97. The Euro 4M RON97 commenced in September 2015, as well as the Euro 5 diesel since November 2014. Following the Malaysian government's directive for the implementation of Euro 4M by 1 January 2020, petrol operators such as Shell, Caltex, Petron and Petronas have introduced the new fuel standard of RON95 petrol at their stations. The price of RON95 had increased steadily since it replaced the lower octane RON92 in 2008 due to the gradual reduction in fuel subsidies by the government (The Central Bank of Malaysia, 2011; Omar Kamil, 2015; Shaari *et al.*, 2018; Yunus *et al.*, 2019).

The RON95 petrol produced lower NO_x emissions by 7.7% compared to RON97 but produced higher emissions of CO (36.9%) and HC (20.3%) (Salleh *et al.*, 2018). The CO emission from RON97 is also reduced from 4% to 3%, while the reduction from RON95 petrol is from 3% to 2.8% based on the fuel characteristics such as density, octane number and lower heating value (Salleh *et al.*, 2018). Engine speed also reduces the CO emissions from the RON95 petrol by 10% lower than the RON97 petrol.

The sulphur limit for petrol and diesel in Malaysia was still high at 500 ppm in 2007, which coincides with the Euro 2 Standard (Atiqah *et al.*, 2018). Ramalingam and Fuad (2014) found that 60% of diesel samples had sulphur levels above 1000 ppm in 2006, followed by 67% in 2007 and 26% in 2009. However, the concentration of sulphur in all diesel samples in 2011, 2012, 2013 and 2014 were lower than 500 ppm and this value was eight times higher than Euro 4 Standards in Peninsular Malaysia (Ramalingam and Fuad, 2014). Atiqah *et al.* (2018) also summarized that Diesel Euro 2 (EDE2) significantly improved the engine fuel consumption by 7.39% and for exhaust emissions, EDE2 produced slightly higher NO_x and CO in Malaysia. In addition, the U.S. EPA informed that approximately 2% of sulphur from diesel fuel also produces PM emission (Stanislaus *et al.*, 2010).

Malaysia introduced the Euro 2M fuel Standard in 2009, whereby the fuel properties are controlled by the Environmental Quality (Control of Petrol and Diesel Properties) Regulations 2007 (Environmental Quality Act 1974, 1974). Since then, all oil companies in Malaysia were required to upgrade their fuel quality to comply with the Euro 2 Standard. Formerly, the sulphur limit was 3,000 ppm for diesel and 1,500 ppm for gasoline (Asian Development Bank 2006). Hence, the Malaysian government recommends lower sulphur to ensure that vehicles use fuels that comply with the Euro 2 Standard. On the other hand, growth in vehicle numbers and modern emission reduction technology demand an adequate supply of low sulphur fuel at levels of 50 ppm and 10 ppm. However, Malaysia moved towards Euro 4 Standard implementations as the next step forward in fuel quality improvement. The Euro 4 Standard restricts sulphur content to a maximum of 50 ppm in fuels (Ramalingam and Fuad, 2014).

The diesel Euro 5M was introduced to the Malaysian market by some oil and gas companies in 2016 (Atiqah *et al.*, 2018). Diesel Euro 5M is a cleaner fuel due to its lower content of sulphur compared with diesel Euro 2M (Stanislaus *et al.*, 2015). The benzene level in the Malaysian Euro 4M is specified at 3.5% by volume, in contrast to the Euro 4 specification for a benzene content of 1% maximum by volume (Asian Clean Fuel Association, 2012). The sulphur content for Euro 4M was set at 50 ppm, similar to Euro 4. The NO_x emissions for Euro 4M is capped at 0.15 g km^{-1} for petrol passenger cars, in comparison to the equivalent figures for Euro 4 at 0.08 g kg^{-1} or the more stringent Euro 5, with NO_x emission capped at 0.06 g km^{-1} (Asian Clean Fuel Association, 2012).

Uncertainty

Among the uncertainties that arise from this study is that only the new motor vehicles registered in the Kuala Lumpur metropolitan area are considered, which is a small scope on the air quality study of pollutant emissions from motor vehicles for a short period from 2010 to 2014. Notwithstanding, this study does not focus on the older motor vehicles, where age is identified as a major contributor to pollution emissions (Caserini *et al.*, 2013), rather, this study examines the fuel consumption in the process of vehicle movement. Zachariadis *et al.* (2001) assumed that both the specific mileage, for example, kilometre per vehicle, and the emission factors are independent of vehicle age and therefore independent of time. Experimental emissions data from in-use cars indicated a clear deterioration in the emission behaviour as cars became older, mainly because of the ageing of their catalytic converters and degradation of their emission control systems (Lawson, 1993; Samaras *et al.*, 1998; Ntziachristos and Samaras, 2000). Therefore, age and technological changes determine the internal dynamics of the motor vehicle population and influence the environmental impact of road transport in various ways. Uncertainty also arises from the average vehicle mileage travelled from the mileage variation, which is estimated up to 3% for NO_x and approximately 12% for CO as well as the emission factors that also contribute to the uncertainty in calculating the emission of pollutants (Baidya and Borken-Kleefeld, 2009).

CONCLUSION

Urban traffic pollution has resulted from various factors such as urbanisation, population, and the economy of the country. The PM_{10} emissions from private cars contribute to air pollution with 214,427 kg released in 2014. The highest PM_{10} emission in Kuala Lumpur was contributed by private cars and motorcycles that resulted from traffic congestion, differences of fuel characteristic in vehicle movement processes, and morphology aspects of the urban background. The growth of EV industry in Malaysia should be encouraged by reducing the exorbitant price of cars, improving the charging infrastructure, and through other strategies implemented by other nations, such as tax incentives on green technological vehicles, which could be one of the ways forward for government agencies to control the negative impact of urban traffic pollution, especially towards human health and urban community.

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