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Changes of Air Pollution and Climate Forcing Emissions due to Fuel Switching to Gasohol in Motorcycle Fleet in an Urban Area of Thailand

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Abstract

This research aims to examine the exhaust emission changed due to fuel switching to gasohol in actual motorcycles (MC) fleet in Nakhon Pathom municipality, Thailand. International Vehicle Emissions (IVE) model was applied by specifying the year 2010 as a base case and the target year of 2020 as Business as Usual (BAU). The parking lot survey, GPS monitoring and MC counting on selected roads during weekday and weekend were conducted. Fuel switching from gasoline octane number 91 to gasohol in all MC fleet in the municipality was set as a scenario according to current Thailand's transport energy policies. Total pollution emissions reduction of the following pollutants after switching to gasohol E10 (10% of ethanol) for all MC in the fleet compared to BAU were obtained: benzene (86%), 1,3-butadiene (69%), VOC (including evaporation) (31%) and CO (29%), while the following pollutants increased: acetaldehydes (>100%), formaldehydes (51%), NOx (9%) and PM (5%). Gasohol use scenario produced larger amount of CO_2 (29%) and CH_4 (9%). Only a small deviation of climate forcer emissions in CO_2-equivalent (reduced by 8% for 20-year and increased by 2% for 100-year horizon) were obtained. Switching to gasohol in MC fleet in Nakhon Pathom municipality unable to achieve air quality and climate co-benefits. Restriction of the local emission factors (EFs) available for adjusting the model's EFs can be influence to the emission calculation. Also, as PM was excluded from the calculation of GWP due to lack of OC and EC information, this can affect the analysis of climate forcer emissions.

Keywords: gasohol; climate co-benefits; motorcycles; IVE model; fuel switching

1. Introduction

Due to worldwide fuel crisis, using of several economically alternative fuels have been vastly promoted in many countries. This leads an increment of world alternative fuel consumption. Gasohol, an alternative fuel, produced from the mixture of gasoline and ethanol. The production of ethanol is related to the utilization of renewable raw materials, e.g., starches, sugarcanes and molasses. In the process of developing alternative fuels, alcohol was regarded as a more prominent engine fuel for internal combustion engines at a present stage for its outstanding physical and chemical properties. Blending ethanol, a kind of renewable and clean oxygenated fuels, with gasoline (ethanol lower than 50% by volume) can be applied in gasoline engines directly without modification (Li *et al*., 2015) including motorcycle (MC). In the context of Thailand, the government has promoted utilization of gasohol by subsidizing its price causing its fast consumption raised from 2012 to 2013 by approximately 70% (4,455 million liters in 2012 and 7,470 million liters in 2013) (DOEB, 2017).

In non-car-centric-culture countries, (e.g., India, China, and some Southeast Asian countries) MC is a popular travelling mode for their citizens resulting in a fast growing MC fleet contributes significantly to air pollution in the cities (Tung *et al*., 2011; Li *et al*., 2015). In Thailand, MC contributes the largest share (approximately 60%) on the land transport fleet. In 2016, there are over twenty million MC registered nationwide, increasing by approximately 18 % as compared to the year 2010 (DLT, 2017). Thus, this fast growth of MC with a majority share on the total vehicle fleet may cause significant gasohol consumption, resulting in significant change in the emissions in the cities, both toxic air pollutants and climate forcers.

Traffic emission inventory is usually conducted using the emission modeling approach. This approach allows cooperating with a large number of vehicles with various engine technologies, fuel and exhausting control devices normally present in a traffic fleet. The International Vehicle Emissions (IVE) model uses the Vehicle Specific Power (VSP) as an indicator of the second-to-second driving pattern. The VSP data account for instantaneous velocity, road grade and acceleration, which are theoretically relate to vehicle emissions better than the average speed considered in other models like COPERT and MOBILE (Wang *et al*., 2008). IVE has been applied in some polluted cities of developing countries, e.g. Mexico City (Mexico), Pune (India), Beijing and Shanghai (China) with promising results (ISSRC, 2010). Performances of the model have been evaluated by Guo *et al*. (2007) and Wang *et al*. (2008).

Previous studies quantified the MC emissions due to the switch, by focusing an individual vehicle emission analyzed from the standard test - chassis dynamometer - in the automotive emission laboratory. However, the study on the traffic emission contributed by the MC fleet with detailed information on the fleet and the emission factors (EFs) for specific vehicle/fuel technology and local driving conditions in the city are rarely reported.

This study attempted to examine the MC fleet and driving patterns in Nakhon Pathom municipality situated in central Thailand. MC emission inventory was produced for the year 2010 and used as a base case. The changes of air pollutant and climate forcer emissions due to fuel switching to gasohol in MC fleet were examined via comparison between the emission in 2020 [business as usual (BAU)] and gasohol switching to all MC fleet in the case study. This can be used as scientific information to develop suitable mobile source emission reduction strategies to meet better air quality in cities.

2. Material and Methods

The principle of IVE model is a combination of the vehicle activity information with vehicle specific EFs as derived by following formula:

$$E_i = \sum N_j \times EF_{i,j} \times VKT_j \times k \quad (1)$$

Where; E_i are the total emissions of pollutant i (in ton); N_j is the number of type j vehicles; $EF_{i,j}$ is the emission factor of pollutant i, vehicle type j (in g/km); VKT_j is the vehicle kilometers traveled for vehicle type j (in km); and k is correction factors, (e.g., base emission adjustment, fuel quality, meteorology, power and driving variables).

The primary data collection was performed in the municipality in April-June 2012 following the IVE method (Davis *et al*., 2005), which consisted of questionnaire survey, traffic counting, GPS (Global Positioning System) recording for on-road MC activities, and personal interview. The secondary data consisted of the total vehicle registration in the area from the Department of Transport, fuel characteristics from the Department of Energy Business, and meteorology from Nakhon Pathom weather station. The obtained data included the registered MC population, engine technology, fuel characteristics, road length, meteorological parameters (hourly ambient air temperature and relative humidity), and on-road vehicle activities (traffic density, driving, and start patterns). Additionally, local EFs obtained from the Pollution Control Department of Thailand (PCD) (PCD and OTP, 2012) were prepared to correct default base EFs in the model IVE. The data were processed and interpreted for the IVE input.

2.1 Data collection and processing

2.1.1 Questionnaire survey

The parking lot survey was conducted to identify the shares of different technology types (IVE technology indexes) of the considered vehicle fleets in the municipality. Questionnaires were distributed to 400 motorcyclists to represent over 47,000 registered MC, providing a 95% confidence estimate following the method presented in Yamane (1973). The questionnaires were shared randomly at three parking lots located at a shopping mall, at a food center and at Silpakorn University. The information regarding the vehicle brand names, ages, engine volume sizes, model years, and odometer readings (total distance traveled) were collected.

2.1.2 On-road driving activities and vehicle specific power (VSP) distribution

Ten main roads (Fig. 1) aligned through different zones in the municipality, (e.g., residential, commercial and educational) were selected for the survey of hourly MC flow and speed. Mechanical tally counters were used to record vehicles at two opposite sides of each selected road. The records were taken daytime from Monday to Saturday (07:00-19:00) and during nighttime on Sunday (19:00-07:00). Each road was recorded every hour with 30 minutes each record time. The corrected traffic flows were fulfilled to the remaining non-recorded periods.

The MC location (longitude, latitude and altitude) and speed were tracked every second over 24 hours using GPS trip recorders, model $747A^+$ (Transystem Inc.), attached on MC of 40 volunteer motorcyclists from various careers and different addresses. The collected data were used to determine the vehicle specific power (VSP) distribution according to the method developed by Jiménez-Palacios (1999). This VSP distribution is a required input for the IVE modeling.

VKT data were determined using the daily distance traveled, extracted from the GPS tracking data. The total VKT for MC fleet was obtained using the vehicle population registered in 2010 and the estimated annual VKT in the fleet.

2.1.3 Engine start distribution

The collected GPS data as described in previous section were also used to specify the start pattern, which refers to the number of starts and the engine soak time - the time interval between two consecutive starts. The start pattern is an important determinant of the vehicle exhaust emission. In this study, a soak time was identified when a zero speed was recorded by GPS for over 4 min. Sitting periods of less than 4 min were categorized as idling (ISSRC, 2010).

2.1.4 Determination of MC emission factors

The model takes into account three emission types: exhaust emission produced during a hot-stabilized engine operation (hot/running emission), exhaust emission during cold engine start (cold start emission), and Volatile Organic Compounds (VOC) evaporative running losses. In this study, the default values of the running EFs, g km^{-1}, and the cold start EFs, g $start^{-1}$ in the model were modified applicable for the local application, using the collected information mentioned above.

2.2 Emission calculations with the IVE model

The model IVE (version 2.0.1) requires three input files - Fleet input file, Location input file and Base adjustment file. The collected primary data and secondary data were processed to prepare the input files to run the model. Other data included the local data of fuel quality and meteorological variables. IVE produced the hourly (and also daily) emissions from a specific vehicle type on each selected route.

According to Thailand's Renewable Energy Development Plan (AEDP), gasohol consumption has been promoted for spark-ignition engine vehicles (DEDE, 2012) together with the rapid growth in using gasohol in recent years. Thus, a scenario was set in which the MC fleet in 2020 in Nakhon Pathom municipality will all consume gasohol E10 (10% of ethanol).

2.3 Analysis of climate co-benefits

MC emission quantities resulted from the energy change scenario were compared with BAU to examine the emission deviation. Co-benefits of the change in fuel consumption scenario as compared to BAU were examined by two aspects, i.e., the emission reduction of air pollution and of radiative forcing agents (climate forcers).

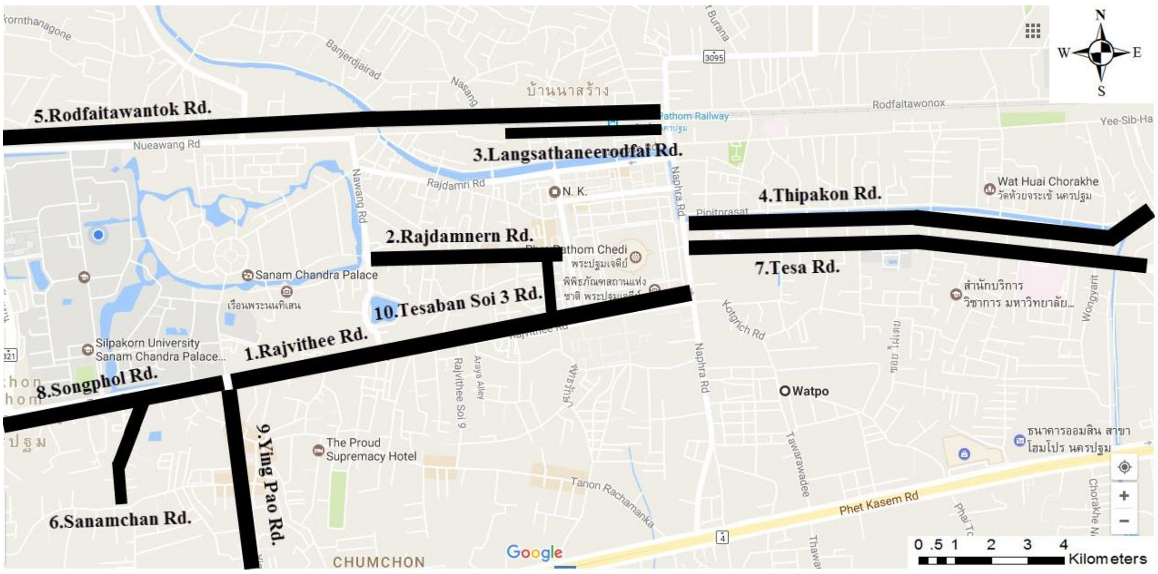

Figure 1. Map of 10 roads where the traffic observation was conducted

Due to the different influence of vehicle emission species on climate, the global warming potential (GWP) metric was used to convert the emissions of different species to a common CO_2- equivalent scale. The GWP values for the climate forcing agents selected in this study (CO_2, CH_4, SO_2, NOx, CO and VOC) were according to the MC emission study in Hanoi presented by Kim Oanh *et al*. (2012). Due to the lack of EC and OC data in the PM emission from MC, their GWP was excluded in this study.

3. Results and Discussion

3.1 Survey results on MC technologies and driving activities

3.1.1 MC technologies

As a result of the survey involving 400 questionnaires, the summaries of the MC distributions by engine technology, traveled distance and fuel type are showed in Fig. 2. The majority of the MC fleet

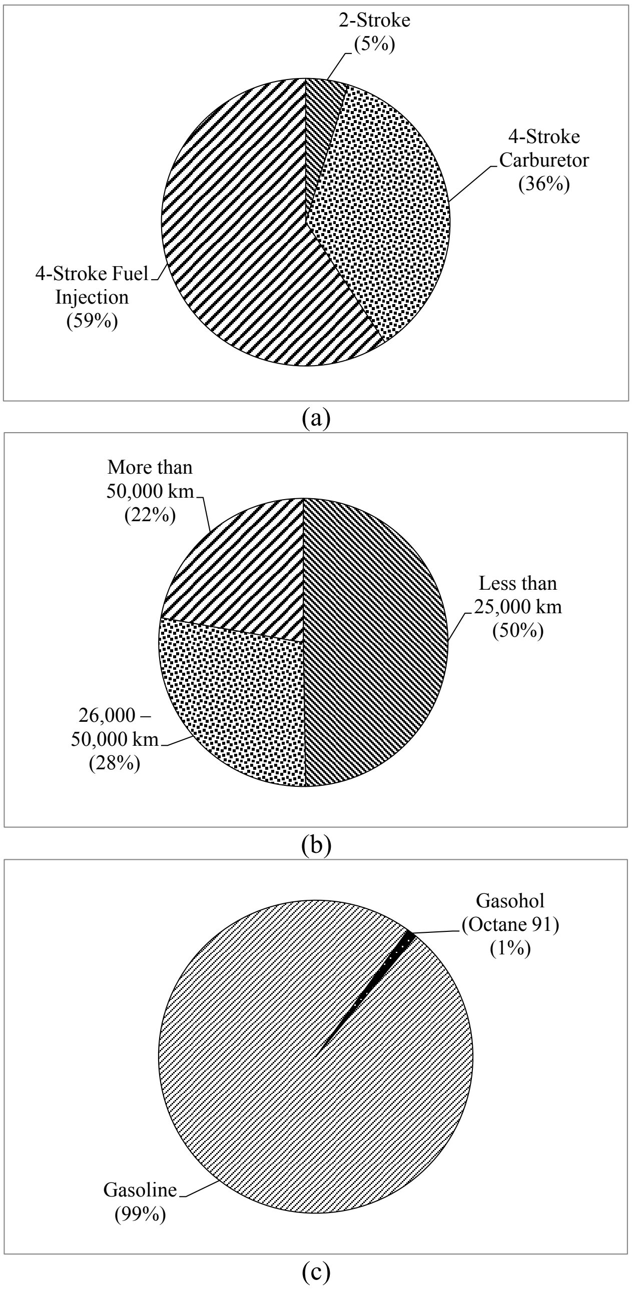

Figure 2. MC distributions by engine technology (a), traveled distance (b) and fuel type (c) in Nakhon Pathom municipality

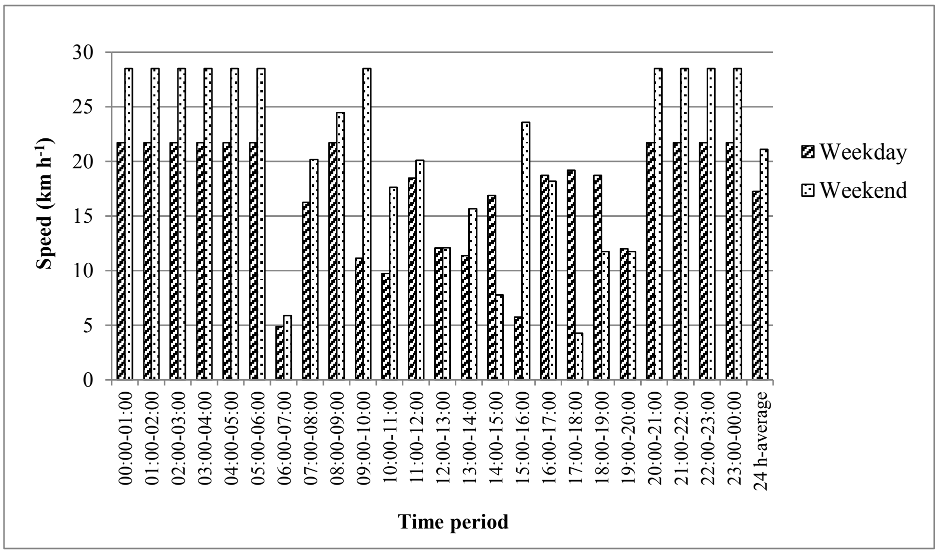

Figure 3. Average hourly speed during weekday and weekend

Remark: From the GPS tracking records, almost all of MC were not operated during 21:00-5:00 in both weekday and weekend, the average speeds between these periods were then assumed to be equaled to the speed at 20:00-21.00.

in the municipality was equipped with four-stroke engines (95%). Among this, they used fuel injection system (59%) followed by carburetor fuel systems (36%). Half of them (50%) had relatively low traveled distance (mileage), i.e., with odometer readings below 25,000 km. MC fleet was mostly using gasoline (99%), while only 1% preferred to fuel gasohol.

3.1.2 Driving activities

Average speed: The average hourly speed of MC compared between weekday and weekend obtained from the GPS survey can be displayed in Fig. 3. The MC speed in the weekday was relatively lower than those in the weekend, (i.e., 17.3 km h^{-1} in the weekday and 21.1 km h^{-1} in the weekend). The MC speed in Nakhon Pathom municipality appeared to be close to the MC speed in arterial and residential streets in Hanoi (22.3 km h^{-1} and 16.9 km h^{-1}, respectively) (Kim Oanh *et al*., 2012). The MC speed in the municipality also varied over the traveling hour in which during the nighttime (20:00-06:00, 25.1 km h^{-1}) was higher than those in the daytime (06:00-20:00, 15.0 km h^{-1}). The occurrence of lower speed during the evening (17.00-19.00) in the weekend as compared to weekday may be due to high traffic density in which the people prefer to go outside for shopping or taking dinner. This is expected to rise the emissions, mainly of the products of incomplete combustion (CO, PM and VOC) (Shrestha *et al*., 2013).

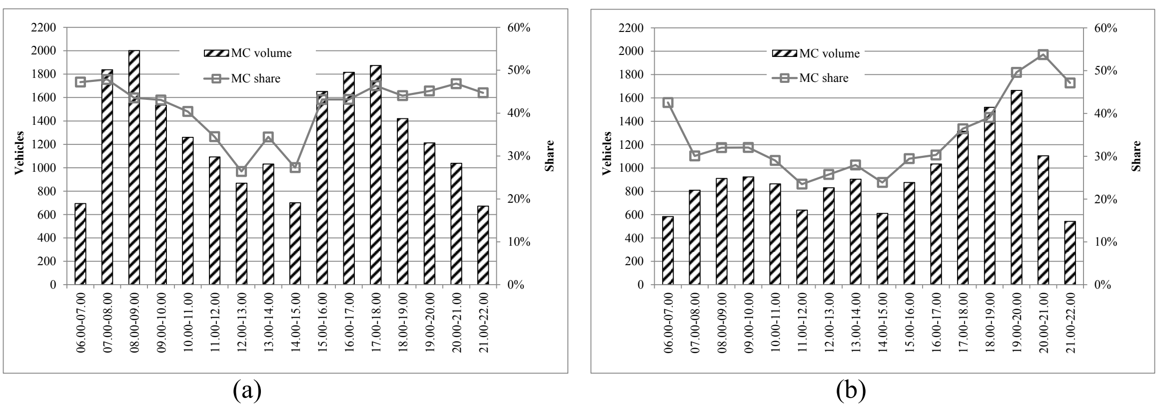

Figure 4. Average hourly MC traffic volumes and its shares in vehicular fleet during weekday (a) and weekend (b)

Remark: Since the observed MC traffic volume and its share during 22:00-5:00 were not so high and significant, the information during this period were therefore not displayed.

Vehicle flow density: As seen in Fig. 4, the average MC volumes in the weekday were dominance during rush hours in the morning (07:00-09:00) and in the evening (16:00-18:00), while in the weekend the higher MC volumes appeared during 18:00 to 20:00. The alignments of hourly MC share in the fleet were likely corresponding to its volumes both in the weekday and weekend. This indicated preference of the people in using MC for a main travelling mode in the municipality. In particular, during late evening to early nighttime (19:00-21:00) in the weekend.

3.1.3 Vehicle specific power (VSP) distribution

The VSP results are summarized in Fig. 5 indicating the different in VSP pattern between weekday and weekend. The VSP distribution in the weekday appeared in the range of lower VSP bins than those in the weekend. All observed bins in the weekday mostly belonged to low engine stress (-1.6 to 3.1 kW/Ton). This was similar to other cities, i.e., Hanoi and Kathmandu (Kim Oanh *et al*., 2012; Shrestha *et al*., 2013). Negative VSP values, e.g., bin number 11 (VSP = -2.9 to 1.2 kW/Ton) indicating the idling conditions in traffic congestions or waiting at the signal lights. Positive VSP values, (i.e., bin number 12 and other) represented positive power of vehicle engine, (i.e., driving at a constant speed, accelerating, and going up a bridge or some combination of all three) (Shrestha *et al*., 2013).

3.1.4 Engine start distribution

The share of engine start of MC analyzed from the GPS surveys are depicted in Fig. 6. The short soak times (<0.25 h) occurred largely in the morning (06:00-07:00) contributing about 50% of the total soak times due to people leave their home for working. The share of this short soak times lasted with continuously declined until in the late evening (19:00-20:00), while those in the longer soak times (1-8 h and >8 h) became larger. As compared to the study in Hanoi (Kim Oanh *et al*., 2012), the short soak times of MC were more pronounce during the daytime and the longer soak times were seen in the nighttime. A long soak period causes cooling the engine, a higher emission is expected during a cold start.

3.2 Emission factors of different engine technologies

3.2.1 MC fleet technologies for IVE

As showed in Table 1, the engine technologies of the MC fleet observed in the municipality were matched with nine default MC technologies categories in IVE. The index type 1245 (small 4-stroke engine, medium usage, catalyst exhaust control and using positive crankcase ventilation) was the highest share by 34.5% while the index types 1173 and 1174 -both having the same properties, i.e., small 2-stroke engine and medium usage, but difference in using levels, i.e., <25 K and 26-50 K km, respectively- were the least abundant, contributing totally 2.0%. Majority of the vehicles

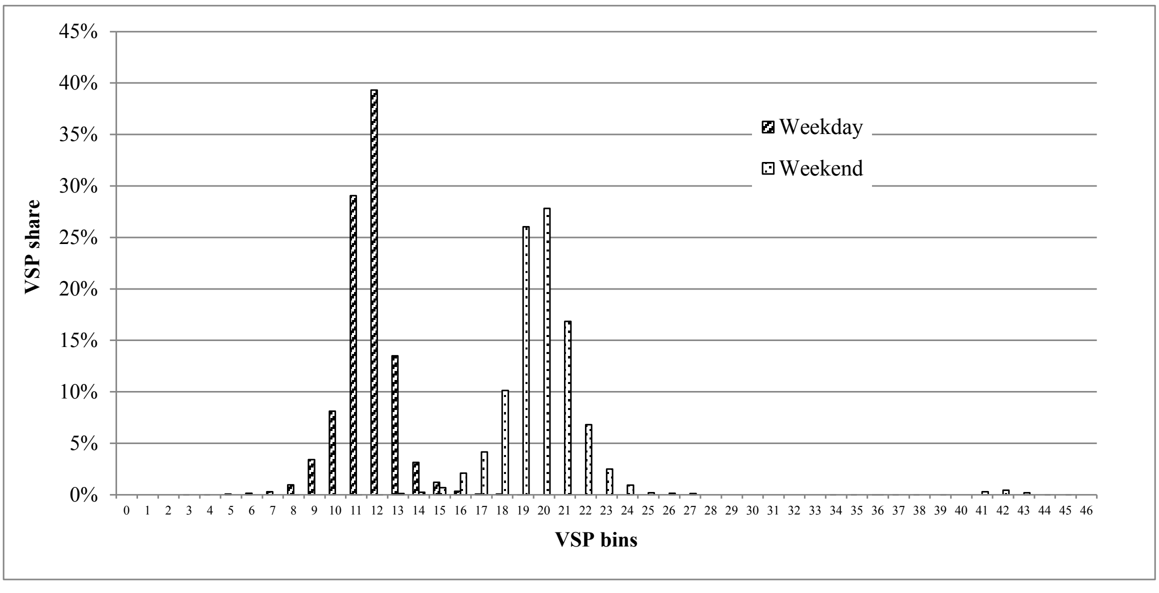

Figure 5. Vehicle specific power (VSP) distribution pattern segregated into weekday and weekend

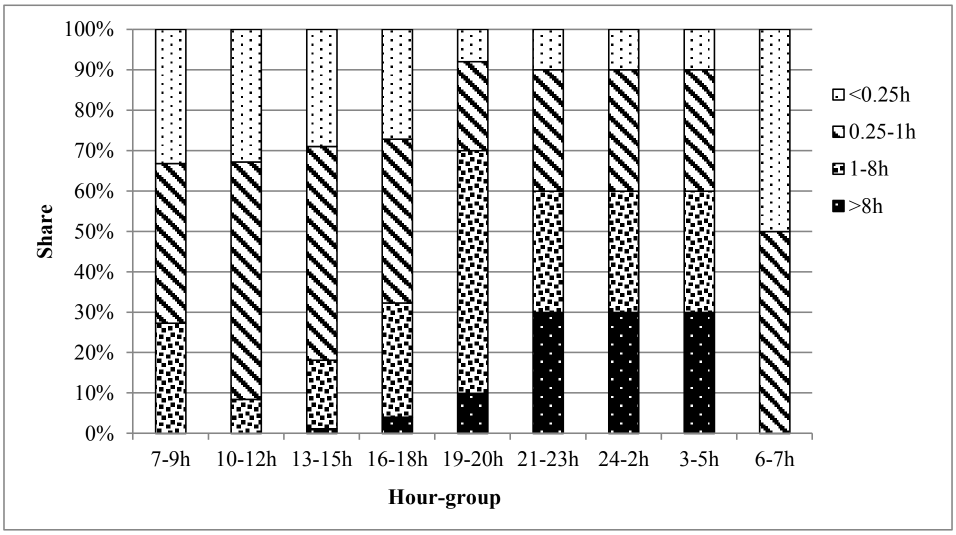

Figure 6. Daily engine soak time distribution for MC
Remark: The engine soak time distribution from the 21h-5h was estimated based on questionnaire observation to the drivers.

(59.5% of the total population) equipped with catalysts (types 1245, 1246 and 1247), while the rest had no exhaust control. There were only 4.8% of the total vehicles still using 2-stroke engine (types 1173, 1174 and 1202).

3.2.2 Composite emission factors for MC technologies

The composite EFs for starting and running for two species, NOx and CO from nine MC technologies of IVE during weekday and weekend are presented in Fig. 7. It can be seen that carburetor vehicles with no exhaust control (Types 1209, 1210 and 1211) produced higher NOx and CO than the others. As compare between engine technologies, 2-stroke engines (Types 1173, 1174 and 1202) emitted lower NOx than 4-stroke engines (the rest types). This is due to 4-stroke engines operating at higher temperature therefore emitting higher NOx. Basically, 4-stroke engine has better combustion efficiency hence producing fewer products of incomplete combustion species including CO. It is unexpected that higher CO emission was seen in 4-stroke engine not in 2-stroke. Among the 4-stroke technology types, the results indicate that fuel injection system equipped with catalytic exhaust controls (types 1245, 1246 and 1247) had lower EFs both the engine start and running. It is fortunately that majority of the MC fleet (59.5%) in the municipality were fall in such technology types.

Noted that base EFs in the model could be partially adjusted with the local EFs. There are a limitation of local EFs database, where the EFs were available only for certain MC technologies at certain average speed and pollutants. Therefore, a sort of EFs used in this study were from the model's default EFs including EFs for gasohol

Table 1. Share of motorcycle technologies matched with IVE default in Nakhon Pathom municipality of 2010

Index	MC Type and Technology	Share (%)
1173	Pt: SmlEng: Med: 2Cyc: None: None: <25 K km	1.0%
1174	Pt: SmlEng: Med: 2Cyc: None: None: 26-50 K km	1.0%
1202	Pt: SmlEng: Med: 2Cyc FI: None: None: >50 K km	2.8%
1209	Pt: SmlEng: Med: 4Cyc Carb: None: None: <25 K km	14.2%
1210	Pt: SmlEng: Med: 4Cyc Carb: None: None: 26-50 K km	12.0%
1211	Pt: SmlEng: Med: 4Cyc Carb: None: None: >50 K km	9.5%
1245	Pt: SmlEng: Med: 4Cyc FI: Catalyst: PCV: <25 K km	34.5%
1246	Pt: SmlEng: Med: 4Cyc FI: Catalyst: PCV: 26-50 K km	15.0%
1247	Pt: SmlEng: Med: 4Cyc FI: Catalyst: PCV: >50 K km	10.0%

Remarks: Nine index types (1173-1247) were described in the IVE model. Pt: petrol; SmlEng: motorcycles; Med: 100-300 cc; 2Cyc: 2-stroke engines; 4Cyc: 4-stroke engines; Carb: Carburetor Fuel System; FI: Electronic Fuel Injection System; Levels of exhaust controls (None & Catalyst); Two levels of evaporation controls (None & PCV- using Positive Crankcase Ventilation); Three using levels (<25 K km, 26-50 K km, >50 K km).

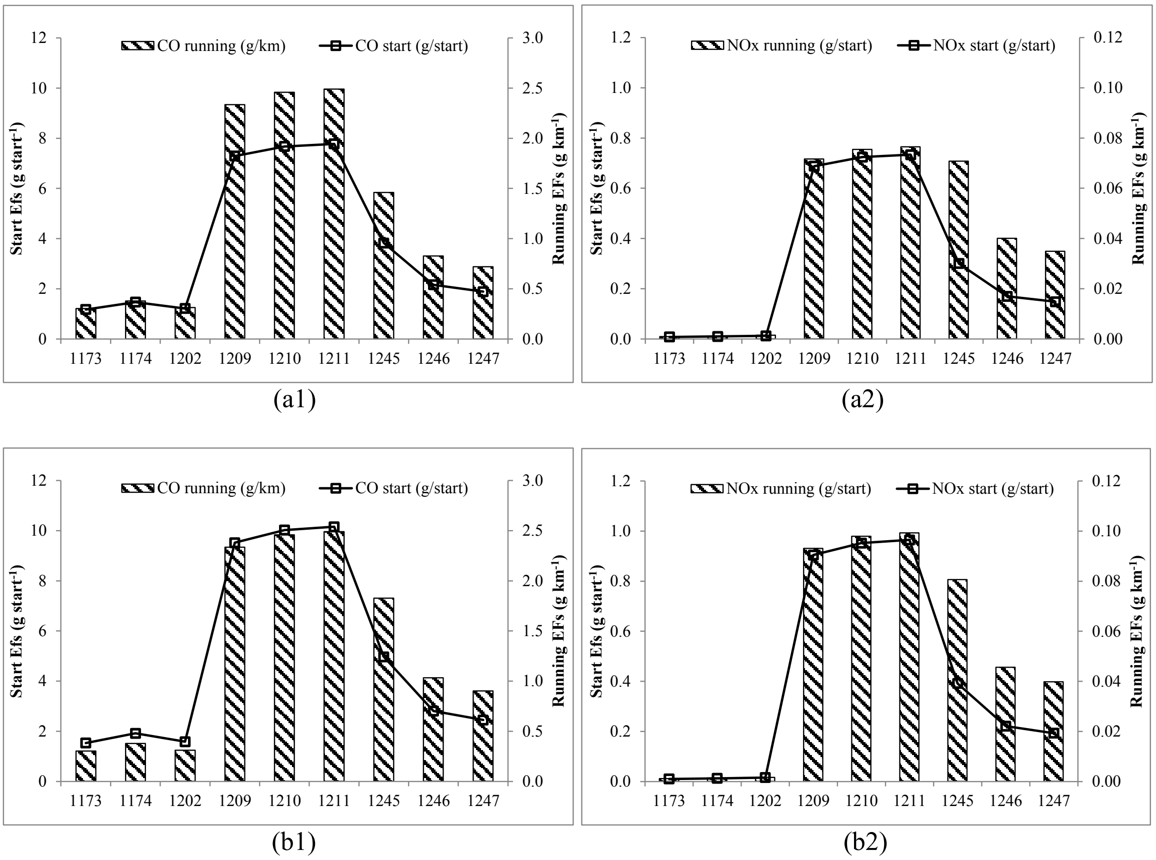

Figure 7. Average running and start EFs of selected pollutants - CO (1) and NOx (2) - for nine technologies of MC fleet in Nakhon Pathom municipality in weekday (a) and weekend (b).

3.3 Emissions of MC fleet and fuel switching to gasohol scenario

3.3.1 Total annual emission

Total emission in 2010 (base case) including running, start and evaporative (in the case of VOC) for the total MC population of 4.7×10^4 in Nakhon Pathom municipality with the total annual VKT of 3.2×10^7 and total number of start of 2.0×10^7 is presented in Table 2. The three largest annual pollution emission species in the base year in metric tons (tonnes) was for CO, followed by VOC and NOx.

3.3.2 Emissions for BAU and fuel switching scenario

Annual emissions for BAU was estimated based on vehicle numbers projected from an exponential relationship derived from annual registered vehicle numbers from 2005 to 2015 with taking into the share of MC number in the municipality to the MC in the provincial levels of 22%, and the account annual MC retired rate of 15%. Therefore, the annual number of MC in the target year of 2020 attained from the calculation was 57,846. It released pollutants (in metric tons) as the same order in the base year of 2010 where CO was the highest, followed by VOC, NOx and PM (Table 2). For the fuel switching to gasohol scenario as compared to BAU, the reductions of CO, VOC and 1,3-Butadiene and Benzene were attained ranged from 29% to 86%, while the rest (NOx, PM, Acetaldehydes and Formaldehydes) increased by 5% to more than 100%.

The climate forcer emissions (GWP) in terms of CO_2-equivalent, in 2020 (BAU) were predicted at about 1.58×10^5 tonnes for 20-year time horizon and about 7.5×10^4 tonnes for 100-year. The GWP emission reduction after the switch was attained by 8% for 20-year time horizon, while in 100-year time horizon it found to be less increase by 2%. The quantification of air pollutant and climate forcer emissions under the scenario obtained in this study indicated that switching to gasohol in MC fleet might not meet air quality and climate co-benefits.

The change in pollution emission after using gasohol in MC fleet obtained from this study was analyzed as vehicle fleet basis. The results are comparable with the previous works in which the emissions of individual vehicles were tested on chassis dynamometer. Anderson (2015) reported that the use of bioethanol blended fuels leads to increases in emissions of formaldehyde and acetaldehyde, with an accompanying decrease in benzene and 1, 3-butadiene emissions. Nitrogen oxides (NOx) emissions are often increased with the use of bioethanol. Principally, due to the amount of oxygen in gasohol, the combustion will be more complete than gasoline combustion. Therefore, emission reduction of CO emission and increment of CO_2 were found. The more excess oxygen, the higher combustion temperature will be occurred where the oxide of nitrogen will be increased. Yang *et al*. (2012) reported that gasohol-fueled MC had average EFs of CO decreased by 20.0%, while NOx and CO_2 emission increased by 5.22% and 2.57%, respectively. It has to be noticed that only 10% of ethanol in gasohol E10 may not create larger effects on the amount of CO and CO_2 as seen in this study (Table 1), where 29% increase in CO_2, whereas same amount of CO reduction (-29%) has been discovered. In contrast, the PM (product of incomplete combustion) was increased (5%) after switching. As well as increment of CH_4 after the switch were seen. These may be due to the restriction of the model's base adjustment process where a sort of local EFs were insufficient for adjusting the model's EFs.

As for VOC, Li *et al*. (2015) found that emission amount of VOCs from MC fueled with gasohol E10 decreased by 18%-31%, while total carbonyls (acetaldehydes included) were 2.6-4.5 times higher than those for gasoline. Emissions of acetaldehydes and formaldehydes, a production of alcohol combustion, can potentially risk to people's health. The promotion of using gasohol as alternative fuel in the fuel policy should be revised with taking into consideration such hazardous emissions. Additionally, acetaldehyde, formaldehyde and nitrogen oxides are important precursors of photochemical air pollution problems such as ozone. Increments of such pollutants can be potentially effects on elevation ozone level in the city (Anderson, 2015). Severe ozone air quality problems have been observed in a number of cities in Thailand, e.g., Pathum Thani (Onchang and Kim Oanh, 2010) and also other cities where gasohol were plenty used like in Brazil.

SOx emission in gasohol consumption was lower than those in BAU (note as non-detectable in Table 2). In principle, SOx is a product of complete combustion. As mentioned earlier, the higher oxygen content in gasohol compared to gasoline enables to meet the more complete combustion. Additionally, SOx emission also depends on sulfur content. According to the fuel standard of Thailand, gasohol had the highest sulfur content followed by gasoline-95 and gasoline-91, thus the release of SOx from gasohol combustion should be higher. Therefore, measurements for SOx EFs should be compared with the base EF default values produced by IVE to serve as a basis for further discussion.

As compared to other cities, the EFs of MC fleet in Nakhon Pathom municipality were lower than those of Hanoi and Kathmandu for all pollutants, except for CO as presented in Table 3. It can be seen that changing to newer emission standard scenarios in Hanoi and Kathmandu enable to attain higher GWP benefits as compared to fuel switching to gasohol in the municipality.

Table 2. Annual emissions (tonnes year^{-1}) of different species in Nakhon Pathom municipality under the fuel switching scenario (MC population in 2010 of 47,444)

Species	Base case (2010)	Business as usual (BAU) (2020)	All MC switching fuel to gasohol	Change (%) as compared to BAU
CO	7,361	8,975	6,355	–29
VOC	1,742	2,124	1,470	–31
NOx	296	361	394	+9
PM	54	66	70	+5
SOx	0.6	0.7	ND	–
1,3-Butadiene	6	7	2	–69
Acetaldehydes	30	36	1,062	+ >100
Formaldehydes	119	145	219	+51
Benzene	67	82	11	–86
CO_2	21,350	26,031	33,567	+29
CH_4	372	454	493	+9
GWP, CO_2 eq. 20-years	129,382	157,750	144,690	–8
GWP, CO_2 eq. 100-years	61,488	74,969	76,238	+2

Remarks: For the base case and BAU, all MC were assumed to use gasoline-91 with the vehicle technologies as obtained from the questionnaire survey. For the fuel switching to gasohol scenario, all MC were assumed to be 4-stroke technology and fuel injection system equipped with catalytic exhaust controls. SOx was considered as SO_2 in GWP calculations. n.d. = non detectable.

Table 3. Comparison of MC fleet composition, average running emission factor and GWP deviation of different scenarios from three cities obtained from the IVE model

	Fleet composition	emission factor (g km^{-1})	Scenario	GWP alteration (%)
Hanoi [a]	Gasoline 4-stroke Euro II: 47%, Euro III: 18%, pre-Euro: 35%	CO: 5.5±2.0 VOC: 1.80±0.77 NOx: 0.20±0.11 PM: 0.09±0.03	EURO2 and EURO3 technology intrusions	19-53 [c] 12-38 [d]
Kathmandu [b]	Gasoline 4- stroke Euro III: 75%, pre-Euro: 25%	CO: 4.6±2.2 VOC: 1.5±0.7 NOx: 0.28±0.13 PM: 0.10±0.05	EURO3 technology intrusion	31 [c]
Nahkon Pathom	Gasoline 4- stroke Euro III: 59%, Euro II: 36%, 2- stroke: 5%	CO: 8.82±6.36 VOC: 0.76±0.42 NOx: 0.09±0.07 PM: 0.03±0.02	Fuel switching to gasohol	-8 [c] 2 [d]

Remarks: [a] Kim Oanh *et al.* (2012), [b] Shrestha *et al.* (2013), [c] CO_2 eq. 20-years, [d] CO_2 eq. 100-years

4. Conclusions

The emission inventory of the MC fleet in Nakhon Pathom municipality in 2010 was conducted using the IVE model. The majority of the MC composed 4-stroke engine fuel injection system with low odometer readings. All most (99%) consume regular gasoline fuel, while the rest using gasohol. The lower average speed was mostly found during driving in the weekday as compared to the weekend. Most of the MC driving in the municipality belonged to low engine stress modes in which weekday was lower than weekend. The short soak times was more pronounce during the daytime and the longer soak times was obtained in the nighttime. Switching to gasohol E10 (10% of ethanol), with excluding PM species, (i.e., EC and OC), apparently unable to gain co-benefits for both cleaner air and climate forcer emission mitigation.

Acknowledgements

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