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Emission Factor of Carbon Dioxide from In-Use Vehicles in Thailand

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Abstract

The objective of determining the emission factor of carbon dioxide (EF-CO_2) from in-use vehicles in Thailand is to gather important data for estimating transport emissions. These data may help develop greenhouse gas management plans for the area. In-use vehicles were tested on a chassis dynamometer by the Bangkok Driving Cycle to quantify CO_2 emissions. The emission factor is defined as the average emission rate for CO_2 per vehicle based on average speed and fuel consumption. The studied vehicle types were the following: heavy duty diesel vehicles (HDDV); light duty diesel vehicles (LDDV); light duty gasoline vehicles (LDGV); and motorcycles (MC) with 4-stroke engines. These vehicles were tested using a variety of fuel types available in Thailand. The study result was found that emissions from the vehicle types were significantly different at the statistic of p-value<0.05. These results can be compared with emission factors of CO_2, including the vehicle types and fuel types from international studies and used in Thailand to promote better efficiency to mitigate greenhouse gas emissions from vehicles.

Keywords: emission factor, greenhouse gas, carbon dioxide (CO_2), in-use vehicles

1. Introducation

Concentrations of carbon dioxide (CO_2), a greenhouse gas (GHG) produced by in-use vehicles, have been increasing in large cities (IPCC, 1995). These emissions are the result of fossil fuel combustion (IPCC, 2007). Developing countries are responsible for an increasing proportion of CO_2 emissions from transport-related activities (Wang, 2010). The number of vehicles and the rate of fuel use in Thailand have increased rapidly, resulting in ever higher emissions of CO_2 and other pollutants. Studies of vehicles in Thailand have focused on calculating fuel consumption and other data. The main objective of this study was to determine the emission factor of CO_2 for vehicles in Thailand. The study investigated heavy duty diesel vehicles (HDDV), light duty diesel vehicles (LDGV), light duty gasoline vehicles (LDGV), and two wheels-motorcycles and three-wheels (tuk-tuks) with four stroke engines (MC). The results were compared with engines operating with alternative fuels in Thailand, including varieties of biodiesel (BX), compressed natural gas (NGV and CNG) and liquefied petroleum gas (LPG). The results can be used to assess means of improving air quality in the megacities of Thailand by reducing and managing CO_2 emissions from vehicle sources.

2. Method

2.1 The Experimental Procedures

This study focused on of four types and engines capacity of vehicles in Thailand: heavy duty diesel vehicles (HDDV), light duty diesel vehicles (LDDV), light duty gasoline vehicles (LDGV), and motorcycles (MC) were included two-wheels of motorcycles and three-wheels of Tuk-Tuks with 4-stroke engines. The emission factor of CO_2 tests were conducted in an emission laboratory (PCD, 2000). The vehicles were further divided into subcategories by vehicle type and fuel type available in Thailand. The details are shown in Table 1.

Table 1. The vehicle types and fuel types in the emission laboratory

In-use Vehicle Types	Number of test	Engines capacity (cubic centimeters, cc.)	Thailand fuel types	Remark types
HDDV	121	4,000-12,350	Diesel, NGV	Buses
LDDV	199	2,200-3,000	Diesel, B2, B5, B20, B50, B100	Pick-ups and Vans
LDGV	166	1,500-3,200	Gasoline 91, Gasoline 95, Gasohol 91, Gasohol 95, LPG, NGV	Passenger Cars
MC	76	110-650	Gasoline 91, Gasoline 95, Gasohol 91, Gasohol 95, LPG	Motorcycles (2-wheels) and Tuk-Tuks (3-wheels) with 4-stroke engines

2.2 The Emission Analyses

The estimation of Emission Factor of CO_2 (EF-CO_2) came from laboratory tests that simulated actual activities encountered during road transport and controlled for factors such as temperature and humidity. The samples were tested on a chassis dynamometer utilizing standard constant volume sampling (CVS) techniques in which the entire volume of exhaust was produced by the engine and transferred to the tailpipe was captured when diluted by the air. The CO_2 concentrations of both the diluted exhaust and the dilution air were measured continually. CO_2 samples were collected for analysis using a non-dispersive infrared analyzer. The CO_2 concentration and fuel consumption were calculated following standard carbon balance procedures. This study used typical Bangkok driving estimates that represent the most common speed for all vehicle types and total vehicle kilometers traveled (VKT) as the control in the analysis system.

2.3 The Emission Factor of CO_2 Measure

Determining the CO_2 concentration from vehicle emissions involves multiplying data by an appropriate emission factor, which is the total CO_2 emission measured divided by the distance traveled estimate (Angiola, 2009), as given by Equation 1:

$$[EF_{CO2}(g/km)] = \frac{total\ CO_2\ Emission\ (g)}{VKT\ (km)} \quad (1)$$

Where the EF of CO_2 is the emission factor of CO_2 in grams per kilometer units, total CO_2 emission is the concentration from the non-dispersive infrared technique in gram units and VKT is the average vehicle kilometers traveled, as taken from Bangkok driving data, in kilometer units. The emission factor is expressed in grams of CO_2 emitted per VKT. Significance levels were calculated at the 95% level. The study examined the mean and standard deviation of the emission factor of CO_2 for each vehicle. The HDDV results were analyzed using an independent t-test between two fuel types and all vehicles with all fuel types. The result was subject to analysis of variance (ANOVA) utilizing the statistical package for social science (SPSS) to translate the data into operational solutions.

3. Results and Discussions

3.1 The EF of CO_2 Compared with Speed and Fuel Consumption

The emission factor measures of CO_2 in grams per kilometer units are given in Table 2. The average speed in meters per second units and fuel consumption in kilometers per liter were sampled for the 4 vehicle types. The emission factors were significantly different in every vehicle type comparison. The emission of CO_2 from vehicles was measured, and a variety of fuel types were used. In-use vehicles of the emission test were separated by vehicle types and fuel types for measured the emission factor. The results show that the average emission factor for HDD vehicles was 1215.5 grams per kilometer, which was higher than that for LDDV, LDGV and MC by 4.2, 6.8 and 25.7 times, respectively. The LDDV reading was higher than that of LDGV and MC by 1.6 and 6.1 times, respectively. The LDGV result was higher than that of MC by 3.8 times. This research shows that the average speed by vehicle type tended to decrease, with HDDV being lower than LDDV, LDGV and MC. However, the fuel consumption tended to increase, with HDDV being higher than LDDV, LDGV and MC, in that order. These results are in accordance with a previous report that the highest emission factor was found in HDDV (Bellasio, 2007). However, in this study show results were as follows:

Table 2. Emission factor of CO_2 on vehicle types, number, speeds and fuel consumption, which were significantly different at $p<0.05$ according to an ANOVA

Vehicles and Fuel Types	Number of test	Average Speed (km/hr)	Fuel Consumption (km/L)	$EF_{average}$ of CO_2 (g/km)	Standard Deviation
HDDV	121				
Diesel	104	19.3	2.4	1150.1	± 196.0
NGV	17	21.6	1.3	1280.9	± 161.8
LDDV	199				
Diesel	153	21.7	9.1	307.2	± 74.9
B2	8	20.9	8.0	338.1	± 52.8
B5	7	31.1	11.0	254.8	± 74.4
B20	15	25.7	9.4	301.6	± 83.0
B50	15	25.7	9.5	309.5	± 85.4
B100	2	35.3	12.4	231.9	± 55.1
LDGV	166				
Gasoline 91	52	21.2	13.0	170.2	± 37.8
Gasoline 95	2	20.9	12.5	192.4	± 32.5
Gasohol 91	37	30.0	11.7	192.5	± 34.4
Gasohol 95	8	34.7	9.4	206.3	± 57.1
LPG	40	22.7	12.7	156.6	± 20.6
NGV (as CNG)	27	25.9	11.9	159.1	± 14.1
MC	76				
Motorcycle					
Gasoline 91	17	32.5	37.4	38.2	± 7.1
Gasoline 95	1	34.4	38.4	41.4	-
Gasohol 91	19	31.2	34.2	40.4	± 9.6
Gasohol 95	15	35.5	37.8	40.1	± 9.0
Tuk-Tuks					
LPG	24	31.3	17.3	76.5	± 9.8

1) The HDDV samples showed an average emission factor ranging from 1150.1 to 1280.9 g/km. The average speed ranged between 19.3 and 21.6 km/hr, with fuel consumption ranging from 1.3 to 2.4 km/L, respectively. For diesel and NGV, the EF of CO_2 levels was 1150.1 and 1280.9 g/km, respectively. Graham (2008) reported that HDDVs using NGV fuel had a higher CO_2 emission than those using diesel fuels.

2) The LDDV samples had average emission factors in the range of 231.9-338.1 g/km. The average speeds ranged from 20.9 to 35.3 km/hr. The fuel consumption ranged between 8.0 and 12.4 km/L. The EF of CO_2 levels for fuel types diesel, B2, B5, B20, B50 and B100 were 307.2, 338.1, 254.8, 301.6, 309.5 and 231.9 g/km, respectively. This result agrees with LDDV dynamometer tests using the new European driving cycle (Pelkmans, 2006).

3) The LDGV samples had an average emission factor ranging between 156.6 and 206.3 g/km. The average speeds ranged from 20.9 to 34.7 km/hr. The fuel consumption was 9.4 to 13.0 km/L. The EF of CO_2 levels for fuel type gasoline 91, gasoline 95, gasohol 91, gasohol 95, LPG and NGV were 170.2, 192.4, 192.5, 206.3, 156.6 and 159.1 g/km, respectively. These results were measured at least two times, and we note that they are less than the average emission factor of LDGV reported by Choi and Frey (2009).

4) The MC samples showed an average emission factor ranging from 38.2 to 76.5 g/km. The average speed

ranged from 31.3 to 35.5 km/hr. and the fuel consumption from 17.3 to 38.4 km/L. The EF of CO_2 levels for the fuel type gasoline 91, gasoline 95, gasohol 91, gasohol 95 and LPG were 38.2, 41.4, 40.4, 40.1 and 76.5 g/km, respectively. Tsai and Weng (2000) reported that MC had a lower emission factor of CO_2 than other vehicles. However, due to economic conditions, the size of these vehicles has tended to increase in developing countries, and we found that overall CO_2 emissions from the MC vehicle type have increased over time.

3.2 The Comparison of EF of CO_2 and Fuel Types

Fig. 1 shows the average emission factor of CO_2 and alternative fuel types as follows: (a) for HDDV, the emission factor for both diesel and NGV were found to differ significantly at the 95% confidence level using a T-test; (b) for LDDV, the results for all fuel types did not differ significantly at the 95% confidence level using an ANOVA, but the emission factor of diesel fuel was significantly different compared with that of B2 and B5; (c) for LDGV, all fuel types were significantly different at the 95% confidence level using an ANOVA, and we found that the emission factor of gasoline 91 was different from gasohol 91 and LPG (note that Gasohol 91 differed from LPG and CNG); (d) for MC, all fuel types differed significantly at the 95% confidence level using an ANOVA, and the emission factor for gasoline 91 in tuk-tuks was different than when using LPG, gasohol 91 and gasohol 95.

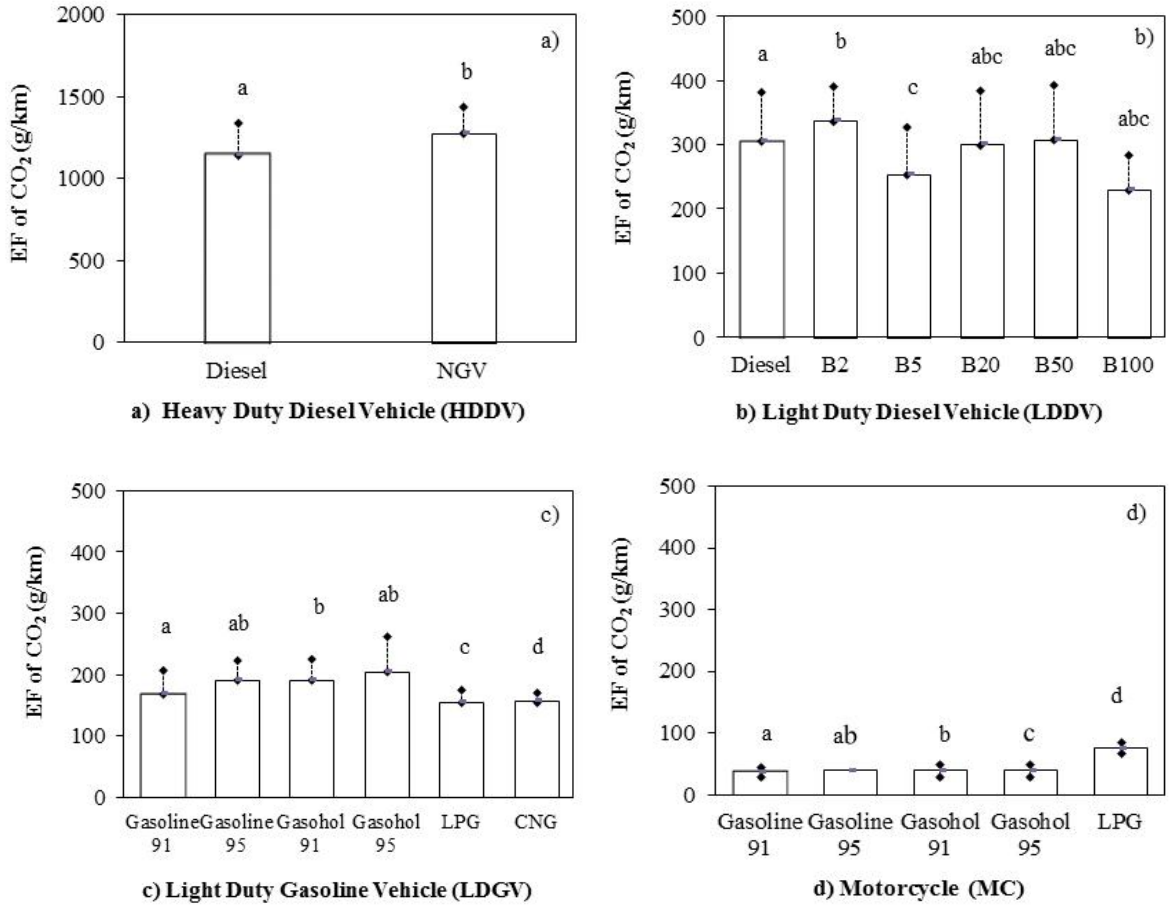

Figure 1. The average emission factor of CO_2 in grams per kilometer by vehicle type: a) HDDV, b) LDDV, c) LDGV and d) MC, which were significantly different at $p<0.05$ according to an ANOVA

These results illustrate the emission factor of CO_2 from motor vehicles measured in kilograms per kilometer. The study used HDDV-, LDDV-, LDGV- and MC-type vehicles and compared our results with those for other emission factor sources. This study will allow organizations and individuals to calculate greenhouse gas effects based on the fuels tested for the emission factor from transport activities. The results tended to agree with

emission factor studies in Europe (Defra, 2009). The emission factor of CO_2 was found to be lower than the guidelines for transportation in the United States of America (USEPA, 2008). The results are shown in Table 3. The emission factor of CO_2 from in-use vehicles of Thailand was determined by testing at an automotive emission laboratory. The data obtained in this study can be utilized in estimating greenhouse gas emission from vehicles and evaluating management methodologies to reduce or mitigate the effects.

Table 3. Comparison of emission factors of CO_2 and fuel type

In-use Vehicles by Fuel Type		Thailand EF-CO_2 (kg-CO_2/km) Tested study	Thailand EF-CO_2 (kg-CO_2/km) Average EF-CO_2	US EPA (2008)	EU (2009)
HDDV					
	Diesel	1.15	1.22	2.78	0.11
	NGV	1.28			
LDDV					
	Diesel	0.31	0.29	0.83	0.27
	B2	0.34			
	B5	0.26			
	B20	0.30			
	B50	0.31			
	B100	0.23			
LDGV					
	Gasoline 91	0.17	0.18	0.58	0.21
	Gasoline 95	0.19			
	Gasohol 91	0.19			
	Gasohol 95	0.21			
	LPG	0.16			
	NGV (as CNG)	0.16			
MC					
	Gasoline 91	0.04	0.048	0.27	0.11
	Gasoline 95	0.04			
	Gasohol 91	0.04			
	Gasohol 95	0.04			
	LPG	0.08			

4. Conclusions

This study shows that the EF-CO_2 of HDDV was 1215.5 grams per kilometer, which is higher than the output for LDDV, LDGV and MC by approximately 4.2, 6.8 and 25.7 times, respectively. The LDDV output was higher than that for LDGV and MC, by 1.6 and 6.1 times, respectively. The LDGV was higher than MC by 3.8 times. These results can be estimated the CO_2 emission from transport section and used in Thailand to promote better efficiency to mitigate greenhouse gas emissions from vehicles.

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