COMPARATIVE ASSESSEMENT OF TRAFFIC FLEETS IN ASIAN CITIES FOR EMISSION INVENTORY AND ANALYSIS OF CO-BENEFIT FROM FASTER VEHICLE TECHNOLOGY INTRUSION

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ABSTRACT

Road traffic remains a major contributor of toxic air pollutants and short-lived climate pollutants (SLCP) in large urban areas in Asia. This paper comparatively analyzes on-road vehicle fleets and the emission for Asian cities produced at the Asian Institute of Technology: Bangkok, Kathmandu, Hanoi and Ho Chi Minh City. Surveys were conducted in the cities during 2010-2014 following the approach generally employed to collect input data for the International Vehicle Emission (IVE) modeling. Large shares of pre-Euro vehicles were still observed in traffic fleets, especially for public bus and truck. Except for small share of Euro 4 in the personal car fleets Euro 3 was generally the most advanced technology level found in these cities. Motorcycle (MC) fleet was the most dominant in the urban traffic. The annual emission of toxic air pollutants (particulate matter and gases, collectively) from on-road fleets in Bangkok; Kathmandu; Hanoi; and Ho Chi Minh City was 3544; 60; 319 and 1605 kt, respectively. The annual emission of GHGs and SLCPs in CO_2 equivalent in these cities was 487,328; 8540; 5920 and 26,315 kt, respectively. If all on-road vehicles in each city would at least compile with Euro 3 then the annual emission would be reduced by 44-85% for toxic air pollutants and 28-42% for climate forcing as CO_2 equivalent. The potential co-benefits would justify the efforts to bring in cleaner on-road vehicle fleets in Asian cities.

Keywords: road traffic, emission inventory, SLCP, co-benefit, Asian cities

Introduction

Road traffic contributes significantly to air pollution load in urban areas of Asian developing countries. Rapid urbanization and economic development in the cities are accompanied with a fast increase in the vehicle fleet to meet the increasing transport demand of the growing population. The road infrastructure does not develop at the same pace. This in combination with the booming of the cities with inadequate urban planning have led to frequent traffic jams, especially during rush hours, which increase the vehicle emission disproportionally.

The low speeds and stop-and-go driving mode make vehicles release huge amounts of toxic air pollutants, particularly the products of incomplete combustion, such as fine particles, volatile organic compounds (VOC) and carbon monoxide (CO). These toxic exhaust fumes are released at the breathing level and in populated urban areas, therefore can lead to a high risk of human exposure. These vehicles also emit greenhouse gases (GHGs) including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), along with acid rain precursors (SO_2 and NOx).

Recently, the so called short-lived climate pollutants (SLCPs) attract increasing attention because they have multiple adverse effects hence emission control for SLCPs would bring in co-benefit in improving air quality and reducing the climate warming rate (UNEP-WMO 2011). The most important SLCP is black carbon (BC) particles which have recently been considered as the second largest warming agent after CO_2 (Bond et al. 2013). About 20% globally emitted BC is generated by diesel powered vehicles, on-road and off-road, including trucks, buses, ships, construction machinery and so on (Bond et al. 2013), hence a cleaner diesel fleet can reduce BC emission substantially.

This paper comparatively analyzes the traffic fleets and on road vehicle emission in 4 Asian cities, namely Bangkok (Thailand), Kathmandu (Nepal), Hanoi and Ho Chi Minh City (Vietnam). The benefits of an optimistic (what-if) scenarios of a faster intrusion of the Euro3 standard in the cities are also analyzed.

Methodology

The EI was done using the International Vehicle Emission (IVE) model which has been developed jointly by the University of California at Riverside, College of Engineering-Center for Environmental Research and Technology (CE-CERT), Global Sustainable System Research (GSSR) and the International Sustainable System Research Center (ISSRC) (ISSRC 2008). Using the input files generated from survey data, IVE model produces the pollutant emission factors (EFs) that are relevant to the local driving conditions and local fleet composition. IVE has been used successfully to generate emission data for several cities in developing countries (http://www.issrc.org/ive/).

IVE modeling requires a large amount of local data to generate the input files for producing relevant EFs to driving conditions in the study areas. IVE has 3 types of input files of which 2 files, the location and fleet files, are mandatory. The third file, the base adjustment, is an optional file and is prepared only when the local measurement data for EFs are available. Such measurement data was not sufficiently available for the considered vehicle fleets in four cities hence the base adjustment file was not used in this study. The EI covered the following IVE emission species: CO, VOC (exhaust and evaporative), NO_x, SO_2, PM_{10}, CO_2, N_2O, CH_4, 1,3-Butadiene, acetaldehyde, formaldehyde, ammonia (NH_3) and benzene, thus lead (Pb) was excluded.

The data collection was generally following the IVE method as described in IVE field data collection activities document (http://www.issrc.org/ive/). In each city, three (3) road types (highway, arterial and residential road) that run through three urban zones (city center, sub-urban and outskirts) were considered. The required data were collected following the IVE data collection method. A summary is presented in Table 1 the detail data collection is presented in Vilaiphorn (2010) for Bangkok, Shrestha et al. (2013) for Kathmandu, Kim Oanh et al. (2012) and Trang (2011) for Hanoi and Van (2014) for HCMC.

Questionnaire survey: The survey for considered fleets (bus, taxi, personal car and motorcycle) was conducted at parking lots, refilling gasoline stations and bus terminals (for buses)

VKT estimation: This study estimated the annual average VKT (Vehicle Kilometers Traveled) using the relationship between odometer readings and vehicle ages (Wang et al. 2007).

Vehicle flow monitoring: Vehicle counting was done manually at nine selected roads, one location per road during both rush and non-rush hours.

GPS survey: This survey was conducted to obtain the vehicle driving and startup patterns. A GPS (GlobalSat DG-100 model) was attached on every surveyed vehicle on each monitoring day.

Table 1. Summary of data collection in four cities

Parameter	**Bangkok**	**Kathmandu**	**Hanoi**	**Ho Chi Minh City**
Survey period	2008-2014	2010	2008	2014
Types of vehicles	Bus, van, taxi, personal car, MC and truck	Bus, van, 3-wheeler, taxi and MC	Bus, taxi, personal car and MC	Bus, taxi, personal car, MC and truck
Number of roads & hours of vehicle counting	9 roads and from 7:00 – 22:00 both weekdays and weekends	4 roads and from 7:00 – 17:30 for weekdays only	9 roads and from 7:00 – 19:00 both weekdays and weekends	9 roads and from 7:00 – 19:00 both weekdays and weekends
Number of questionnaires	1100	540	1300	1750
No. of vehicles for GPS survey	51	59	23	28

Quantification of co-benefits

The EI for the urban fleets was produced for the base case. An optimistic faster technology intrusion scenario was considered which assumed that all vehicles in each city would be at least conform Euro3. The emissions of toxic air pollutants and associated global warming potential (GWP) in CO_2 equivalent (CO_2 eq.) under these scenarios and the base case were compared.

The CO_2 equivalent of an emission was calculated using Equation 1.

$$\text{GWP of a scenario } (CO_2 \text{ eq.}) = \sum E_i \times GWP_i \qquad \text{(Eq. 1)}$$

Where,
E_i: emission amount of species i (mass, tonne/year)
GWP_i: global warming (+) or cooling (-) potential of species i

Only GWP for the 20 year horizon was estimated because the impacts of SLCPs should be more pronounced over this shorter period. The GWPs for GHGs and SLCPs used in this study are those considered relevant for Southeast Asia (SEA) and listed in Table 2. Because the IVE model does not produce OC and BC emissions directly, this study estimated the OC and EC emissions as the fractions of exhaust PM emitted from diesel and gasoline vehicles. For diesel vehicles, the values used in this study were based on the measurements for the diesel fleet in Bangkok, Thailand (Kim Oanh et al. 2009): EC = 0.46 PM and OC = 0.2 PM. The OC and BC fractions in the PM emission from gasoline vehicle exhaust were estimated using the data provided by US EPA (US EPA 2012): OC = 0.78 PM and BC = 0.19 PM.

Table 2. GWP values used in this study relative to CO_2 emission mass

Pollutants	**GWP**	**Remark**
	20-year	
CO_2	1	
CH_4	72	Fuglestvedt et al. (2009)
N_2O	289	IPCC (2007b)
NO_x, per kg N	43	Fuglestvedt et al. (2009)
VOC	14	Collins et al. (2002)
CO	6	Derwent et al. (2001)
BC	3,200	Bond et al. (2013)
OC	-240	Fuglestvedt et al. (2009),

Results and Discussion

Fleet information and driving activities

The overall information on the fleets in 4 cities for different types of vehicles is presented in Table 3 which shows the active population of five major vehicle types (bus, taxi, motorcycle, personal car and truck) along with age, daily VKT and total VKT in the surveyed years.

Table 3. General information of on-road traffic in 4 cities

Motorcycles				
Parameters	**HCMC, 2013**	**Hanoi, 2008**	**Kathmandu, 2010**	**Bangkok, 2013**
Number of active vehicle	5,004,831	2,339,519	394,420	1,298,765
Average age and range	4.6 (1-29)	3.56 (1- >10)	4.3 (1-27)	5.7 (1-20)
Average driving per day (km/day/vehicle)	19.4	20.3	**15**	16
Total VKT (thousands km/day)	97,094	47,492	5,916	20,780
Taxi				
Number of active vehicle	17,802	12,189	6,206	83,742
Average age	6 (2-10)	2.11 (1-4)	9.5 (1-21)	3.6 (0-14)
Average driving per day (km/day/vehicle)	123.5	157	**87**	280
Total VKT (thousands km/day)	2,199	1,914	540	23,448
Personal car				
Number of active vehicle	315,943	100,359		1,202,499
Average age	7.6 (0-16)	2.44 (1-8)	NA	5.3 (1-20)
Average driving per day (km/day/vehicle)	33.4	42	**NA**	70
Total VKT (thousands km/day)	10,552	4,215	NA	84,175
Bus				
Number of active vehicle	3,358	1,118	11,328	18,850
Average age	6.4 (1-11)	6.31 (2-10)	8.9 (1-47)	8.8 (1-30)
Average driving per day (km/day/vehicle)	196.5	212	**96**	137
Total VKT (thousands km/day)	660	237	1,087	2,582
Truck				
Number of active vehicle	185,501			1,284,645
Average age	11.7 (1-27)	NA	NA	6.2 (1-17)
Average driving per day (km/day/vehicle)	31.4	NA	**NA**	112
Total VKT (thousands km/day)	5,825	NA	NA	143,880

The technology distribution in the fleets is shown in Figure 1 which shows that only a small portion of Euro4 found in the personal car (PC) fleet in Bangkok. For other types of vehicles and PC in other cities the most advance technology level was Euro2 or Euro3, and there were large fractions of pre-Euro in every fleet.

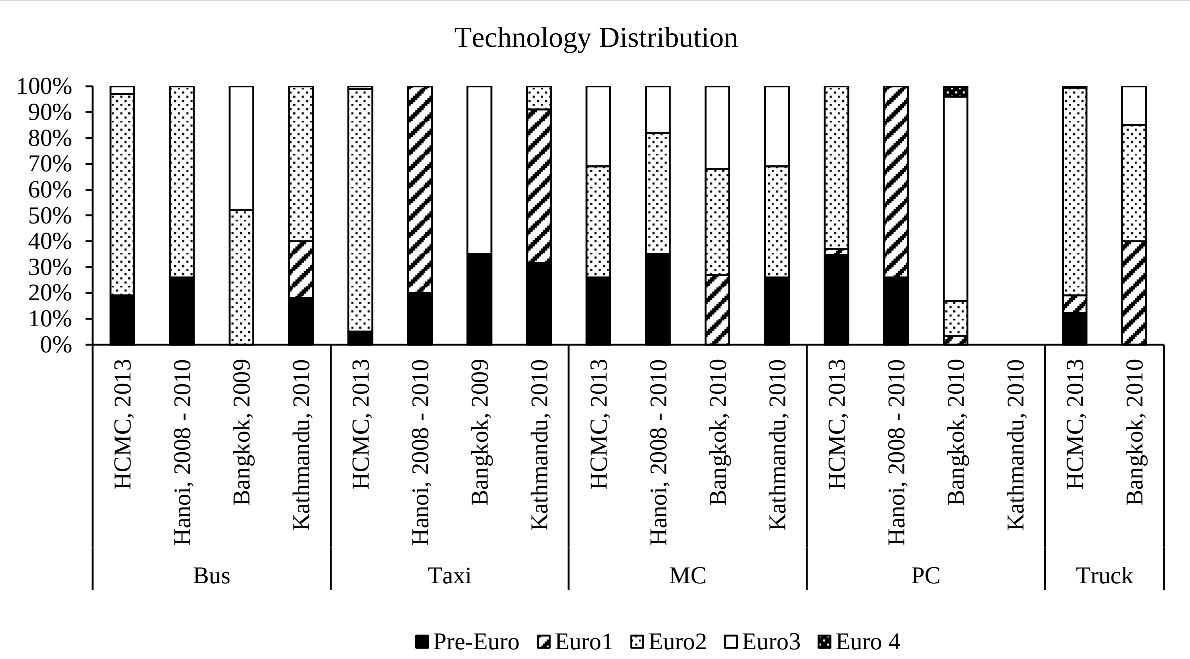

Figure 1. Technology distribution in different fleets of 4 cities (no PC information for Kathmandu)

Emission inventory results for the base case

The emission inventory (EI) results are presented in Figure 2 for the respective base year when EI was conducted. The shares in percent and the total annual emission (values in Gg/year) are given. The emission presented was for passenger fleets (bus, taxi, PC, MC) for all cities except for Kathmandu for which PC was not included in the survey. HCMC had the highest annual emission, followed by Hanoi and Bangkok while Kathmandu had the lowest emission. It is noted that HCMC had the largest MC fleet followed by Hanoi. Bangkok had the largest population of other vehicle fleets (Table 2) and also more advanced fuel quality (CNG, LPG) than other 3 cities where only diesel and gasoline were the most common. Lower emission in Kathmandu was due to its lower vehicle numbers and also because the PC was not included in the results presented. The running emission factors for PM produced from Kathmandu buses were the highest due to its low speed and old vehicles with high mileage (Shrestha et al. 2013).

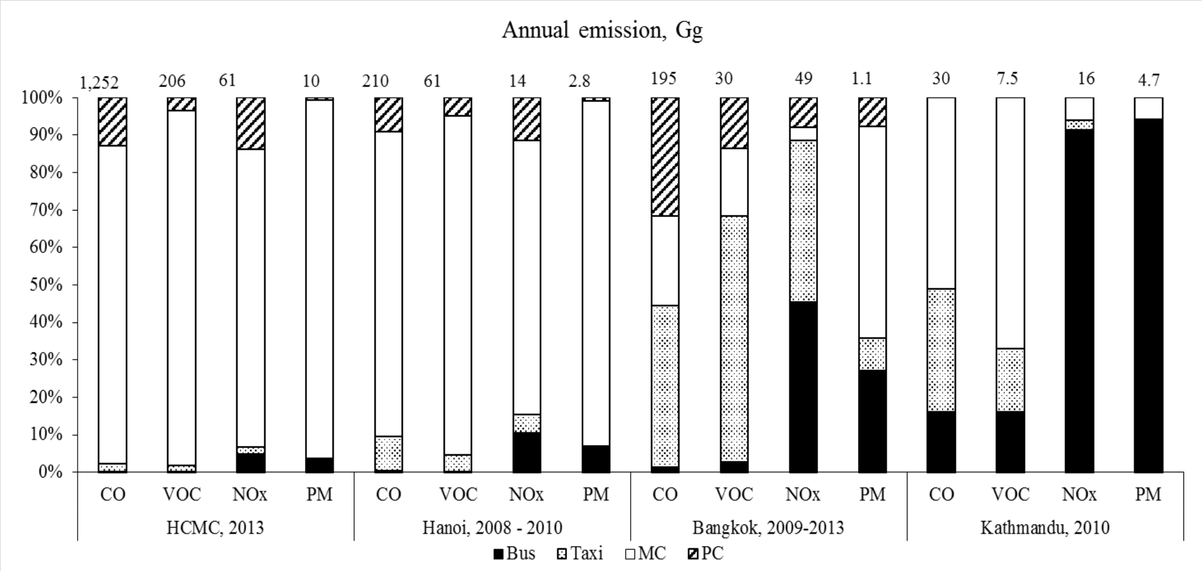

Figure 2. Annual emission for considered vehicle fleets in the cities (PC was not included in EI for Kathmandu)

The EI results for BC and OC (Figure 3) show that the highest BC was from Kathmandu owning to its high emission of PM from the diesel bus fleet. In HCMC and Hanoi, the MC had high shares of BC emission. In Bangkok mots of BC was from the diesel-power buses.

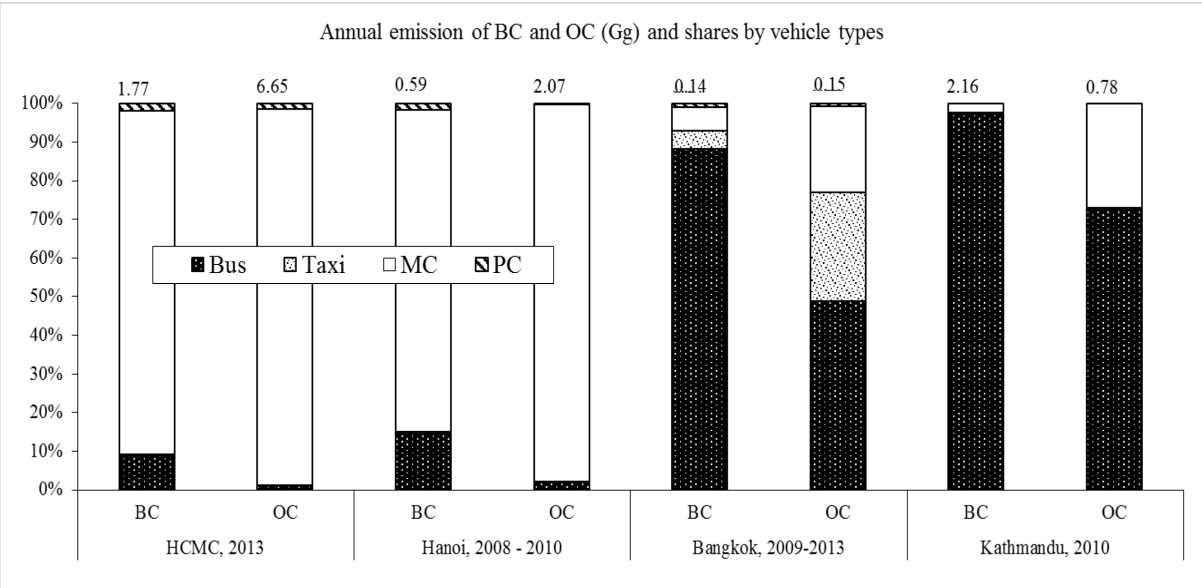

Figure 3. Emission of BC and OC in four cities

Air quality and climate co-benefit of faster Euro3 intrusion

This scenario assumes that all considered vehicles in a city would at least conform Euro3 and old vehicles would be replaced by new vehicles while the total VKT and start numbers remained the same as the base cases. This would bring in co-benefits in reduction of emission of air pollution in each city and also GWP reduction as seen in Table 4. The reduction in emission of toxic air pollutants collectively would be 44-85% in the 3 cities presented while the reduction in GWP of the fleet emission would be 28-31%.

Table 4. Reduction in emission of air pollutants and GWP under Euro3 scenario as compared to the base case

	Emission reduction Scenario Euro3, %		
	Hanoi	**HCMC**	**Kathmandu**
CO	89	57	51
VOC (exh+evap)	92	42	48
NOx	36	57	31
Sulfate	44	45	-4
PM	61	60	45
BC	*68*	*69*	*46*
OC	*28*	*50*	*46*
CO_2	-7	3	-2
N_2O	44	5	-627
CH_4	97	39	40
Air Toxics	87	43	-39
NH_3	32	38	25
Total Pollutants (excluding BC, OC, GHG)	**85**	**55**	**44**
Total GWP	**28**	**42**	**31**

Note: fleets considered in the scenario for HCMC were bus, PC, taxi, MC and truck, for Hanoi were bus, taxi, PC and MC, and for Kathmandu were bus, taxi, van, 3-wheeler and MC.

Conclusions

Large shares of the vehicle fleets in the 4 cities were still of pre-Euro engine technologies. Only a small fraction of personal car fleet in Bangkok had equipped with Euro3. Major types of fuel were still diesel and gasoline in HCMC, Hanoi and Kathmandu while substantial shares of clear fuels of CNG, LPG and gasohol were observed in Bangkok. The vehicles had a wide span of ages and mileage with the most aged vehicles being buses in Kathmandu. This in couple with the extreme low speeds observed in the Kathmandu Valley had resulted in high emission factors, especially for PM and BC in the Valley. If all vehicles in each city would be conform Euro3 standard then substantial benefits to air quality and climate mitigation would be achieved.

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