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HEALTH CO-BENEFITS OF CLIMATE CHANGE MITIGATION FOR THE BUS SYSTEM OF HA NOI

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Abstract. The potentiality of co-benefits for the bus system in Hanoi is determined using IVE and AirQ$^+$ models. The real–world driving data of the five bus routes of Hanoi, namely No. 9, 18, 25, 32 and 33, were recorded by GPS technique with the update rate of 1 Hz. Information on the technical conditions of vehicles was collected by questionnaires. The traffic volume was determined by vehicle counting. GPS data were processed and used to simulate the emission for the base state and three scenarios of air pollution control of Hanoi bus system. Co-benefits of climate, air quality and health were deterned. The obtained results show that either the fuel switching or the tightening of the emission standards brings significant benefits for environment and health.

Keywords: co-benefits, driving data, Hanoi bus, IVE model, AirQ$^+$ model.

Classification numbers: 3.4.5; 3.5.1; 3.6.2.

1. INTRODUCTION

Transport is one of the main sources of air pollutants in big cities, especially in developing countries. Transport is, therefore, considered to have harmful impacts on health. Well-designed transport policies can lead to far-reaching reductions in traffic-related health risks from air pollution. The transport sector is also a major source of greenhouse gas (GHG) emissions, and thus it is an important focus of climate change mitigation. Hence, actions to reduce GHG emissions often involve reducing co-emitted air pollutants, bringing co-benefits for environment and human health. In other words, to optimize the social, economic and environmental benefits that can be derived from mitigation, transport mitigation strategies need to be examined in the light of co-benefits concept. However, co-benefits studies are still scarce, especially health benefits, in Viet Nam. The lack of data on environmental and health co-benefits in Viet Nam leads to the difficulty of decision-making. To partially fill up the gap, this study is aimed at the assessment of potentiality of environmental and health co-benefit for the bus system in Hanoi associated with air pollution control scenarios proposed.

2. METHODOLOGY

The methodology of this study is presented in Figure 1.

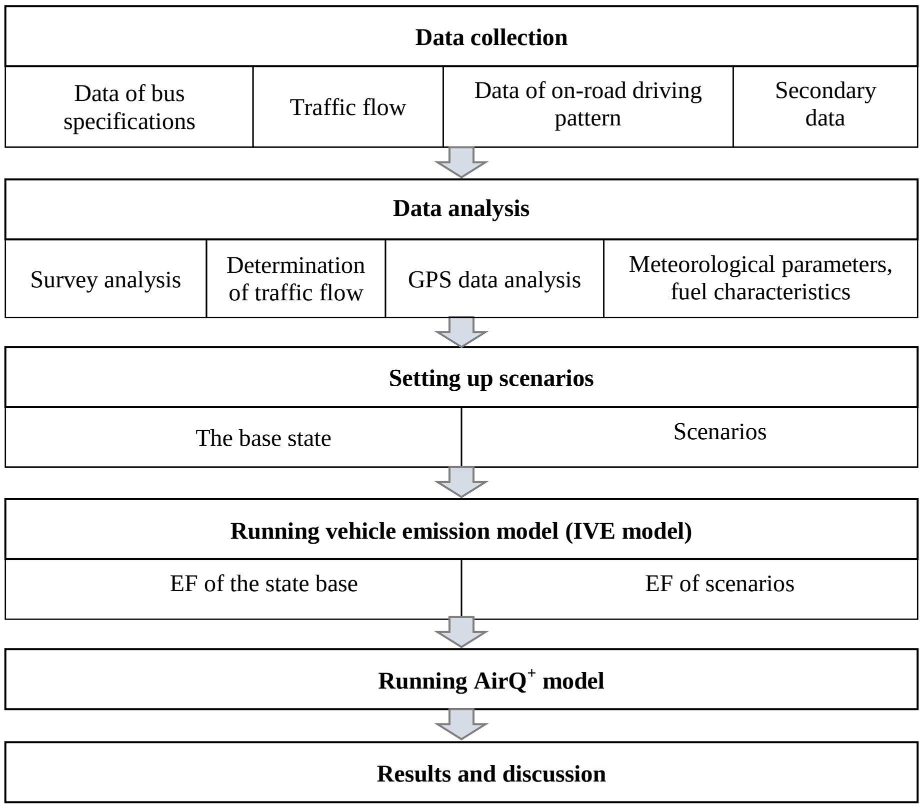

Figure 1. Framework of methodology.

2.1. Study area

The study focused only on 12 urban districts of Hanoi. Based on the requirements of the model, three areas in Hanoi including upper income (Area A), commercial (Area B) and lower income (Area C) were chosen. In each area, three road types are required consisting of higways, arterials and residential roads. Based on the analysis of social and economic conditions of these districts, areas and roads were selected as shown in Table 1. Five bus routes, shown in Table 2, were also selected to reflect the scope of the study.

Table 1. The information of areas and roads used in this study.

Area	Highway (Group 1)	Arterial road (Group 2)	Residential road (Group 3)
A	Nguyen Van Cu street	Nguyen Thai Hoc street	Hang Voi street
B	Giai Phong street	Chua Boc street	Phuong Mai street
C	Tran Duy Hung street	Pham Hung street	Trung Kinh street

*Table 2.*The information of the five bus routes used in this study.

Route	Type of route	Starting point	Finishing point	No. of vehicles per route(*)
09	Closed	Hoan Kiem Lake	Hoan Kiem Lake	18
18		National Economics University	National Economics University	15
32	Radial	Giap Bat Coach Station	Nhon Transfer Station	33
25	Ordinary	Nam Thang Long Car Parking	Giap Bat Coach Station	17
33		My Dinh Coach Station	Xuan Dinh	14
Note: (*)*Data were collected on Oct.25, 2015 from the website of Transerco (BUS-WEBGPS)*				

2.2. Data collection and analysis

2.2.1. Data of bus specifications

Data of bus specifications of Hanoi (the characteristics and age of vehicles, air pollution control technologies, the type and quality of fuel, etc.) were collected from the website of Transerco (BUS-WEBGPS) and by questionaires. Number of questionnaires used was 100 ones. This information used to figure out technical specifications of buses in Hanoi including the fuel type, gross vehicle weight rating, air/fuel control, exhaust control, vehicle age and traveled kilometers. Some information about the bus specifications is presented in Figure 2.

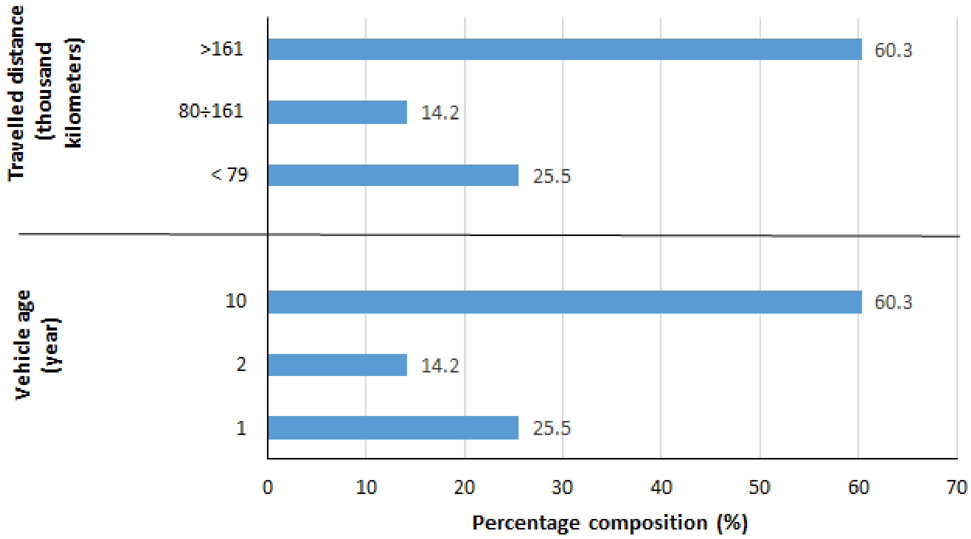

Figure 2. The bus specifications of Hanoi.

All buses in Hanoi use diesel oil and control the air/fuel ratio by the direct injection.

2.2.2. Data of bus flow

Bus flow was obtained by counting in each of the nine roads that are mentioned in Table 1. Counting activities were conducted for three periods of time in a day (7 am – 9 am, 10 am – 11 am, and 1 pm – 3 pm) on a number of dates in October 2015. Counting was carried out every 15 minutes with following 10 minutes off.

2.2.3. Data of on-road driving pattern

On each of the bus routes, a bus was selected. A GPS, Garmin etrex vista HCx, was used to collect data of on-road pattern of buses including cold-start, steady-state cruise, acceleration, deceleration, idle etc. The data were recorded on this bus, continuously from the starting point at around 6 am to the finishing point at around 8pm, the same in weekdays and weekend.The data were recorded with the time step of one second to avoid losing information. These data were collected from July to October, 2015. MapSource software was used to convert data collected from GPS into Excel files, including two fields of data: time and speed.

The collected GPS data were processed to remove errors that can appear in the process of capturing raw data such as sudden signal loss, data spiking, signal white noise, and zero speed drift while maintaining the integrity of the raw source data [1, 2]. In this study, the proposed filtration process for improving the quality raw GPS data is presented in Figure 3.

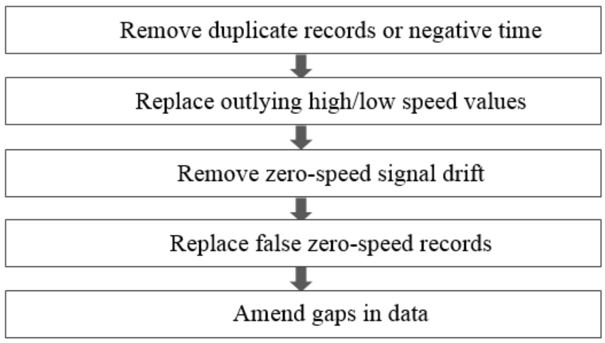

Figure 3. Flowchart of GPS data filter.

All these tasks are done by the Matlab software. After that, the filtered GPS data were used to determine emission factors by using IVE model.

2.2.4. Secondary data

Secondary data include fuel characteristics, meteorological (annual average temperature and humidity) and altitude of Hanoi. The characteristics of diesel fuel were collected from Petrolimex while the other data were taken from the meteorological website http://www.nchmf.gov.vn.

2.3. Setting up scenarios and running emission model

2.3.1. Setting up scenarios

Based on the reality of Viet Nam and the trends of the world, three scenarios were proposed as follows:

- Scenario 1: 100 % of existing buses of Hanoi are switched to use CNG (CNG);

- Scenario 2: 100 % of existing buses of Hanoi are switched to use LPG (LPG);
- Scenario 3: 100 % of existing buses of Hanoi meet the emission standard of EURO IV (EURO IV).

It is assumed that the bus fleet and on-road driving pattern in three scenarios proposed are the same as the base state.

2.3.2. Running emission model

In this study, IVE (International Vehicle Emissions) model was used to simulate the vehicle emission based on the processed GPS data. The IVE model was developed by the US Environmental Protection Agency (US.EPA). This model was also used in our previous studies [3-5].

The precision of the IVE model was evaluated by Guo Hui et al. and the results demonstrated a good agreement between the IVE model and on-road optical remote sensing measurement (all the correlation coefficients, r^2, between emission factors obtained by the former and the later were above 0.8) [6].

All collected primary data were processed to prepare two input files (the Fleet file and the Location file). For the Fleet file, we need to import the vehicle fleet component that is classified based on the vehicle age, technology group and traveled distance. For the Location file, we must import vehicle active data, data related to fuel (type and characteristics) and meteorological parameters. The vehicle active data are imported through the distribution of bins (including 60 bins) which are determined depending on the calculation of two very important parameters, they are:

+ **VSP** (Vehicle Specific Power) is defined as a power per unit mass to overcome road grade, rolling and aerodynamic resistance, and inertial acceleration. Equation (1) is the initial equation for VSP [7]:

$$\text{VSP (kW/ton)} = v\times[1.1\times a+9.81\,(\arctan(\sin(\text{grade}))) + 0.132]+0.000302\times v^3 \quad (1)$$

where: a – acceleration (m^2/s); v – speed (m/s); grade – road grade (radian)

+ **ES** (Engine stress**)** is the parameter correlating the vehicle power load experienced over the past 20 seconds of operation, from v_{t-5} to v_{t-25}, and the implemented RPM (Revolution Per Minute) of the engine. The Engine stress is calculated using Equation (2) [7]:

$$\textbf{ES}\text{ (unitless)} = \text{RPMIndex} + (0.08\text{ ton/kW})\times \text{PreaveragePower} \quad (2)$$

where: PreaveragePower = Average ($VSP_{t-5 \text{ to } t-25sec}$) (kW/ton).

RPMIndex = $Speed_t$/SpeedDivider (unitless).

2.4. Computation of results

2.4.1. Co-benefits of climate and air quality

Co-benefits of climate and air quality are calculated following the methodology, which is presented in detail in our previous studies [3-5].

2.4.2. Co-benefit of health

To evaluate health benefits related to the air pollution control scenarios of Hanoi bus system we assumed that the people are exposed only to pollutants which are emitted from bus system activities. In addition, all other factors are equal in all scenarios except the EF in each scenarios. Co-benefit of health associated with the proposed scenarios is, therefore, estimated based on the changes in ambient air pollutant concentrations, that are converted into the changes in health effects, as illustrated below.

Changes in EF → Change in amount of emission → Change in ambient pollutant concentrations → Change in health effects

To calculate the concentration of air pollutants at a location which are related to the emissions of roadway we used the improved air pollutant dispersion model from roadway traffic of Régis et al. [8]. The mathematical equation of this model is as follows:

$$C(x,y,z)=\frac{Q}{2\sqrt{2\pi}u\cos\theta\delta_z(d_{eff})}\exp\left(\frac{-z^2}{2\delta_z^2(d_{eff})}\right)\times \left[\operatorname{erf}\left(\frac{(y-y_1)\cos\theta-x\sin\theta}{\sqrt{2}\delta_y(d_1)}\right)-\operatorname{erf}\left(\frac{(y-y_2)\cos\theta-x\sin\theta}{\sqrt{2}\delta_y(d_2)}\right)\right] \quad (3)$$

with: $d_i=(x-x_i)\cos\theta+(y-y_i)\sin\theta; \quad d_{eff}=x/\cos\theta,$

Where: C is the pollutant concentration in $g.m^{-3}$ of the receptor at location (x, y, z), x is the distance from the source along the wind direction in m, y and z are the cross-wind distances from the plume centerline in m, u is the wind velocity in $m.s^{-1}$, Q is the emission rate in $g.s^{-1}$, and δ_y and δ_z are the standard deviations representing pollutant dispersion in the cross-wind directions in m, x_i and y_i the coordinates of the source extremity i (with i = 1 or 2) in the source coordinate system, the angle θ represents the angle between the normal to the line source and the wind direction.

$AirQ^+$ model was used to estimate the health effects. This model is proposed by World Health Organization for the assessment the health effects by air pollutants such as $PM_{2.5}$, PM_{10}, NO_2, O_3, black carbon (BC). $AirQ^+$ also enables users to load their own data of air pollutants which not included in $AirQ^+$ if relative risks (RRs) are available [9]. In this study, the RRs are used based on the epidemiologic studies of Viet Nam and some other countries in Asia (Table 3).

Table 3. Relative risks for selected pollutants.

Health outcomes	Relative risks (with the increase of concentration of 10 $\mu g/m^3$)			Sources
	NOx (as NO_2)	SO_2	$PM_{2.5}$	
Hospital admissions for acute lower respiratory infections (ALRI) in young children	-	1.077	-	[10]
Mortality from all non-accidental causes	1.014	1.019	1.009	[11, 12]
Cardiovascular mortality	-	-	1.016	
Respiratory mortality	-	-	1.022	
Acute conjunctivitis	1.06	-		[13]
Chronic conjunctivitis	1.10	-	-	
Note: the health risks associated with short-term exposure				

3. RESULTS AND DISCUSSIONS

Average emission factors (EF) of Hanoi bus system in weekdays and weekend for the base state were obtained and presented in our previous study [14]. In this paper, these EF are used as the base data to estimate co-benefits related to different scenarios of air emission control.

3.1. Benefits of air quality

Benefits of air quality of the emission control scenarios for the bus system in Hanoi are assessed and shown in Table 4.

Table 4. Benefits of air quality.

Pollutants	EF of base state (g/km)	Scenarios					
		CNG		LPG		EURO IV	
		EF (g/km)	Changes (%)	EF (g/km)	Changes (%)	EF (g/km)	Changes (%)
CO	3.68	8.69	136.1	22.63	514.9	0.30	-91.8
VOC	1.27	0.21	- 83.5	0.59	-53.5	0.05	-96.1
NOx (as N)	19.05	0.54	- 97.2	0.63	-96.7	7.89	-58.6
SO_2	0.15	0.00035	-99.8	0.0027	-98.2	0.013	-91.3
PM_{10}	2.96	0.004	-99.9	0.01	-99.6	0.50	-83.1
CO_2	1471	158	-89.3	1122	-23.73	1192	-18.9
CH_4	0	1.89		0.23		0	
Note: Minus (-) is reduced; VOC = $VOC_{tailpipe}$ + VOC_{evap}							

It can be seen from Table 4 that almost all EF in three proposed scenarios are decreased comparing with the state base with some exceptions.

CNG and LPG generally contain practically zero S (except trace amount in the odourant (mercaptan) added to gas for safety reasons) and N, whereas DO contain a certain amount. That is why switching from DO to CNG or LPG can reduce the almost emission of SO_2 and a part of NOx emission in terms of the fuel NO. Additional part of NOx emission in terms of the thermal NO might be reduced resulting from the lower temperature of combustion in the engine. CNG and LPG actually contain nearly zero VOC. In addition, these fuels have simpler molecules than that of DO then their combustion is more likely to be completed than DO, leading to lower VOC and PM including PM_{10}.

The S content of DO,which is currently used for road vehicles in Viet Nam including buses, is 500 ppm. When this fuel meets EURO IV standard, it has to have a maximum of 50 ppm of sulfur [15], meaning that SO_2 emission can be reduced over (500-50)/500 = 90 %. Furthermore, when the buses meet the EURO IV standards, their exhaust is stricly controlled/treated leading to lower emissions of other air pollutants including VOC, NOx, CO and PM.

The reduction of NOx and VOC emissions lead to the decrease of the formation of ground ozone as well as secondary PM such as PM_{10} and $PM_{2.5}$ in the ambient air. This point is very important in terms of air quality improving.

The increase of CO and CH_4 in the scenarios 1 and 2 can also be explainable. CH_4 is the major component of CNG and the second component of LPG but it is absent in the diesel oil. In addition, it is reported that, for low carbon fuel such as CNG and LPG, higher emission of CO is found due to less mixing of air and gaseous fuel [16]. The results in Table 4 are in conformity to the study of Abdullah Yasar et al. [16].

3.2. Benefits of climate

The reduction of GHG emissions as CO_2eq for the proposed scenarios is presented in Table 5.

Table 5. Emission of CO_2eq and respective reduction associated with the selected scenarios (for 20 years).

Item		Base state	Scenarios		
			CNG	LPG	EURO IV
This study	Emission of CO_2eq, ton/year	316	22.7	80.6	123.1
	Reduction of CO_2eq, ton/year		293.3	235.5	193.0
	Reduction of CO_2eq, %		92.8	74.5	61.1
Trang et al. [3]	Reduction of CO_2eq (%)		82.1	85.8	-

It can be seen from Table 5 that, although the emission factors of almost pollutants of Hanoi bus system presented in this study (data were collected in 2015) is smaller than those reported by Trang et al. (data were collected in 2010-2011) [3], the total emission of CO_2eq in the former is higher. This can be explained by the fact that the bus fleet in Hanoi has been increased rapidly in recent years. In addition, the amount of CO_2eq in this study is calculated for 20 years, not for 100 years as in the study of Trang et al. [3].

The obtained results in Table 5 also show that all the scenarios lead to the reductions in the CO_2eq emission, from 61.1 % to 92.8 %, in which fuel switching from diesel oil to CNG is the best option in terms of climate change mitigation. The use of CNG fuel releases less greenhouse gases than that of LPG or diesel fuel.This finding is in conformity to that reported by [17, 18].

Using the online greenhouse gas equivalencies calculator tool of US Environmental Protection Agency (EPA) we can see that the reduction of 293.3 ton CO_2eq/year in the sceanrio 1 is equivalent to greenhouse gas emissions from 61.9 passenger vehicles driven for one year, or 702.9 miles driven by an average passenger vehicle, or 93.1tons of waste recycled instead of being landfilled [19].

3.3. Benefits of health

In this study we used $EF_{running}$ of air pollutants which are emitted directly from the exhaust, so PM is predominantly found to be in the fine fraction ($PM_{2.5}$) [20, 21]. $PM_{2.5}$, therefore, is used to estimate benefits of health. In addition, the EF of PM_{10} in the exhaust is used for the replacement of the EF of $PM_{2.5}$.

The benefits of health are assessed based on the reduction of health effects related to the reduction of pollutant emissions in the proposed scenarios.In this study, the health effects are calculated only for the exposure by $PM_{2.5}$, SO_2 and NO_xin short-term. These pollutants are normally used in studies about the effects of transport-related air pollutants on mortality and hospital admissions [22, 23]. The obtained health benbefits are shown in Table 6.

Table 6. Health benefits of reducing $PM_{2.5}$, SO_2 and NOx emission for the selected scenarios.

Health effects (Health indicators)		Health data (All ages)			
		Base state	CNG	LPG	EURO IV
Total mortality (Mortality of all causes related to air pollutants from transport)	Number of cases	138	109	109	120
	Reduction (%)		21	21	13
Cardiovascular mortality	Number of cases	57	52	52	53
	Reduction (%)		8	8	7
Respiratory mortality	Number of cases	77	71	71	72
	Reduction (%)		8.3	8.2	6.9
Acute conjunctivitis	Number of cases	216	121	121	160
	Reduction (%)		44	44	26
Chronic conjunctivitis	Number of cases	327	189	190	247
	Reduction (%)		42	42	24
Note: Estimating health effects is based on short exposed population size of 100000 persons					

Using health indicators as shown in Table 6, we can see that the health benefits are obtained in all proposed scenarios, the total mortality are reduced (down to 13 % for the total mortality).

Among scenarios proposed, health benefits obtained in the scenarios of fuel switching are higher than those of the tightening of emission standards because the emission factors of CNG and LPG for air pollutants that effect strongly on human health are smaller, meaning that CNG and LPG are cleaner fuels. The scenarios of fuel switching can reduce the total mortality down to 21 % and acute conjunctivitis down to 44 %. According to WHO, transport-related air pollutants that most affect health include PM_{10} and $PM_{2.5}$ and those that can cause mortality such as BC, O_3 and $PM_{2.5}$ [24]. Therefore, as the reduction of PM_{10} in the scenario 2 is slightly higher than that in the scenario 3, then $PM_{2.5}$- related mortality in the former is eleven cases lower than that in the later. This leads to reconfirm that, in the transport, the effects of particulate matter (PM) on human health is the harmfulest. This identification is similar to the conclusion of Mazouzi [22], and Susan et al. [25]. In the study of Susan et al., they determined that BC mitigation measures (synonymous with PM_{10} reduction) could avoid approximately 98 % of deaths [25]. In addition, the emission of PM is the biggest problem of diesel vehicles. In this context, switching to cleaner fuels would contribute positively in the reduction of health effects related to transport activities.

4. CONCLUSIONS

The study determined quantitatively the co-benefits of health, climate and air quality for Hanoi bus system associated with the three scenarios of air pollution control. It is found that the fuel switching from diesel oil to either CNG or LPG as well as the tightening of the emission standards to EURO IV significantly contribute to the migtigation of climate change, the improvement of air quality and the reduction of health effects. Among these measures, the fuel switching from diesel oil to CNG create the highest benefits for the environment and health. The results also indicate that among air pollutants emitted from transport activities, PM has the strongest effect on human health. This point become more important becausePM is a main air pollutant of diesel vehicles including the buses. Therefore, switching to cleaner fuels such as CNG and LPG would improve significanly the quality of life and environment. The results obtained in this study can be used as a scientific basis for an integrated air quality management in general and for air pollution control of Hanoi bus system in particular.

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