CLIMATE AND AIR QUALITY CO-BENEFITS OF IMPROVING TAXI SYSTEM IN HA LONG CITY, QUANG NINH

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ABSTRACT

Co-benefits of improving taxi system in Ha Long city, Quang Ninh province were studied. Three areas and nine routes in the urban area of Ha Long were selected for conducting this study. Information on the technical specifications of the taxi system was collected by 130 questionnaires. Taxi volume on nine selected routes was determined by vehicle counting. Real-time information on the driving behavior of taxis was obtained by GPS. Collected data were processed to generate input files to run IVE model associated with the base state and 4 selected air pollution control scenarios. Emission factors of air pollutants of the taxi system in Ha Long for these cases were determined. Climate and air quality co-benefits were quantified.

Keywords: co-benefit, Ha Long, IVE model, taxi, air quality, climate, emission factor.

1. INTRODUCTION

Traffic activity is the largest source of air pollution in cities of Vietnam including Ha Long as it contributes about 70 % air pollutants [1]. To deal with this problem, there are several approaches, in which, co-benefits one is proved to be an efficient in many developed countries. Co-benefits refer to multiple benefits achieved in different fields resulting from one policy, strategy, or action plan. Co-benefits to climate change mitigation are those that also promote positive outcomes in other areas such as concerns relating to the environment, energy and economics [2]. In order to support decision-making of concerning authorities, it is needed to have scientific basis/data. However, no such data are found for Ha Long city. To partly fill up the gap, this study is aimed at the assessment of climate and air quality co-benefits for the taxi system in Ha Long associated with selected air pollution control scenarios.

2. METHODOLOGY

Steps of conducting this study are presented on Figure 1.

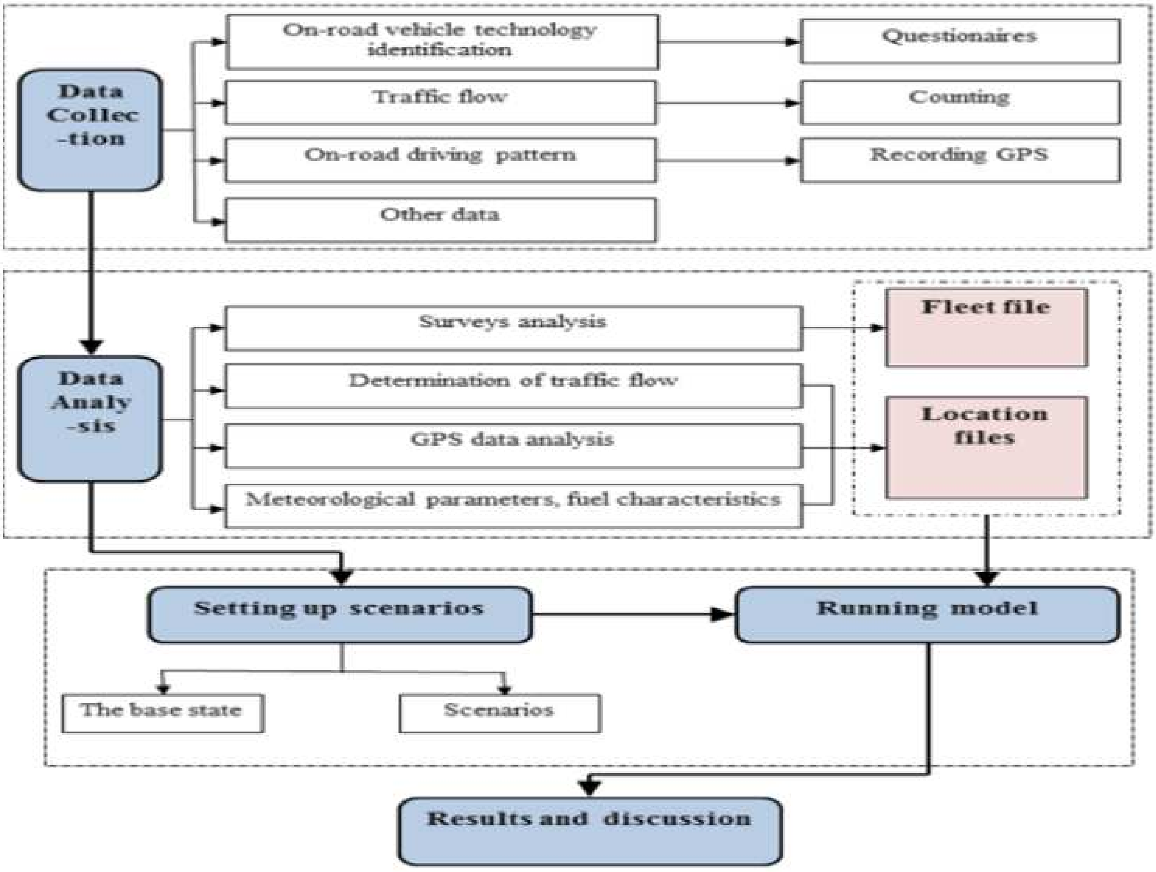


Figure 1. Framework of methodology.

2.1. Study area

The study was conducted in the urban area of Ha Long city. Based on the requirements of the model and actual conditions, three areas of the city including upper income (Area A), lower income (Area C) and commercial area (Area B) were selected. In each area, three roads representing for three groups being highway (Group 1), arterial (Group 2) and residential (Group 3) roads were selected. They are Highway 18, Ha Lam and Nguyen Van Cu (Group 1); Tran Hung Dao, Bui Thi Xuan and Hai Phuc (Group 2); To Hien Thanh, Bai Muoi and Hai Ninh (Group 3) as presented on figure 2.

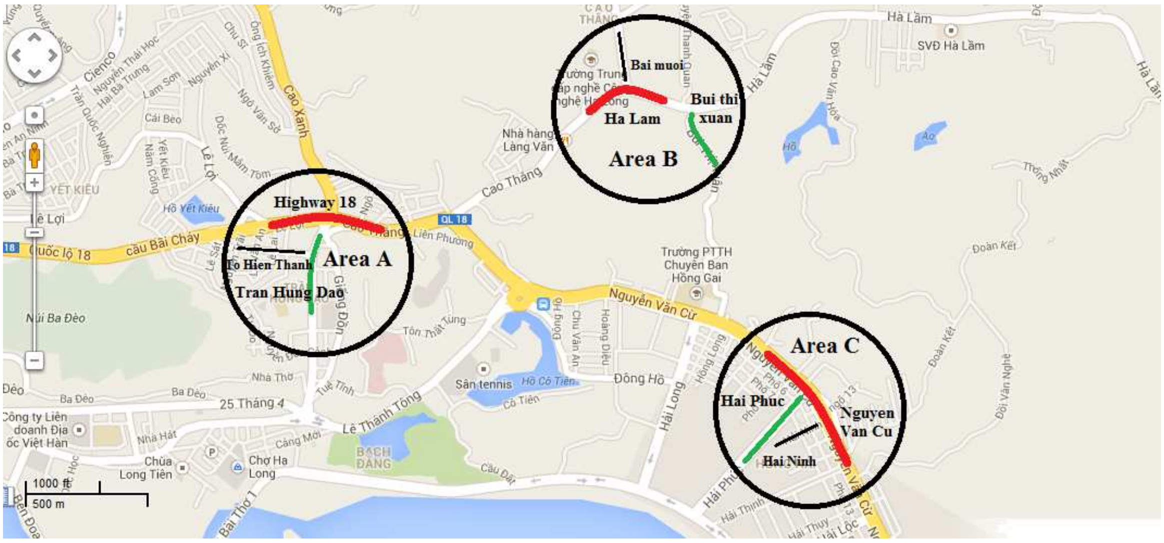


Figure 2. Three areas and nine routes in the study area,

2.2. Data collection and analysis

Data collection was conducted in June 2013.

Vehicle volume: Vehicle volume was obtained by counting the number of taxis on each of nine selected roads in three time periods (7 am – 9 am, 10 am – 11 am, and 1 pm – 3 pm). Counting was carried out every 15 minutes with following 10 minutes off.

Technical specifications of vehicle fleet: 130 questionnaires were used to collect technical information about vehicle fleet. The number of questionnaires is based on the number of taxis which is 618 [3]. The survey was conducted at stop-over sites inside as well as outside the selected areas. These questionnaires were, then, analyzed to figure out technical specifications of taxi fleet including type of fuel, gross vehicle weight rating (GVWR), air/fuel control, exhaust control and number of kilometers traveled. The results of the analysis were used as input data for Fleet file.

Driving behavior: Speed, location, time break between engine starts-up were recorded by a GPS, Garmin Oregon 550. Recording for each taxi was continuously conducted for the whole day (24 h) of weekdays and weekends. The recording was conducted on 2 different taxis, from 6^{th} – 28^{th}, June 2013. The data were used to determine two very important parameters in IVE model being vehicle specific power (VSP) and engine stress:

VSP is defined as the power per unit mass to overcome road grade, rolling and aerodynamic resistance, and inertial acceleration. Equation (1) is the initial one for VSP [4]:

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

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

Actually, in the cities, if the route is long enough then the average of the road grades can be considered to be zero. Therefore, for convenience, the collection of the road grades is ignored. It is the same in this study.

Engine stress is used to express the correlation between the vehicle power load in the past 20 seconds of operation (from t = -5 sec to t = -25 sec) and engine revolutions per minute (RPM). Engine stress is calculated using Equation (2) [4]:

$$\text{Engine Stress (unitless)} = RPM_{Index} + (0.08\text{ton/kW})\text{preaveragePower} \quad (2)$$

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

$$RPM_{Index} = \text{Velocity}_{\ t=0}/\text{SpeedDivider (unitless)}.$$

Secondary data: Characteristics of the fuel (gasoline) were collected from Petrolimex while hourly meteorological parameters (ambient air temperature and humidity) on the surveyed days were taken from the website wunderground.com.

2.3. Setting up scenarios and running IVE model

IVE model (International Vehicle Emission model) was developed by the US Environmental Protection Agency (US. EPA) and Office of International Affairs. The model is used to estimate the emission of air pollutants and greenhouse gases from motor vehicles. It is designed specifically to be able to meet flexible needs of developing countries in an effort to determine air emissions from mobile sources. Input files of IVE model include 3 data files being Location, Fleet and Base Adjustment [4]. In this study, due to limitations of time and equipment, only Location and Fleet files were developed based on data collected, while the file of Base Adjustment used the default data of IVE. Output files of IVE model show the emission load of pollutants (per day or hour) associated with Running and Start-up. In IVE model, pollutants are classified into three groups: air quality (group1), toxics (group2), and global warming (group3) [4]. This study focused on the groups 1 and 3.

Five cases were selected to run IVE model. They are the base state, switching fuel from gasoline to compressed natural gas (CNG), switching fuel from gasoline to liquefied petroleum gas (LPG), meeting the emission standards of Euro 3 (Euro 3) and meeting the emission standards of Euro 4 (Euro 4). It is assumed that the taxi fleet and driving behavior in the four selected scenarios are the same as the base state.

2.4. Computation of results

Co-benefit of climate is estimated based on the reduction of carbon dioxide equivalent (CO_2 eq) between each scenario and the base state. CO_2 eq is calculated using Equation (3) [4]:

$$CO_2eq = \sum_{v,i} A_v \times N_v \times \mathrm{EF}_{v,i} \times P_i \qquad (3)$$

where: A_V - Average activity (km travelled per year per vehicle) of the vehicle of type v; N_v - Number of vehicles of type v; $EF_{v,i}$ - Emission factor of pollutant i for the vehicle of type v, P_i - the global warming or cooling potential of pollutant i which is called the global warming potential (GWP). Pollutants used for the calculation of CO_2 eq in this study include CO, VOC, NO_x, SO_2, CO_2, N_2O and CH_4. The GWP of these pollutants for 20 years are presented in table 1.

Table 1. The global warming potential of selected pollutants (for 20 years).

Pollutants	CO_2	CO	VOC	NO_x (as N)	SO_2	CH_4	N_2O
GWP	1	6	14	43	-57	72	289
Source		[5]	[6]	[7]	[8]	[9]	[10]

Co-benefit of air quality is estimated based the difference of EFs between each scenario and the base state.

3. RESULTS AND DISCUSSIONS

3.1. Emission factors of Ha Long taxi system

Emission factors (EFs) of Ha Long taxi system in weekdays and weekends for the base state are shown in table 2.

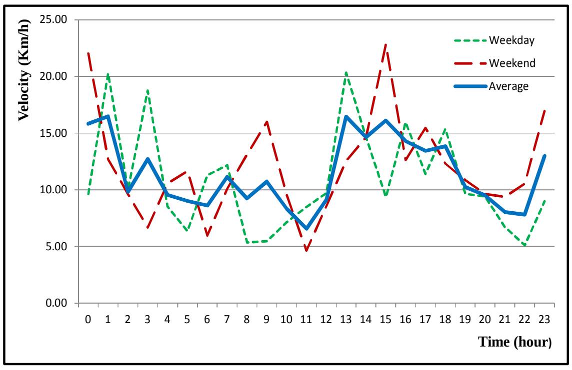
Table 2. EFs of Ha Long taxi system (g/km).

Pollutant	Weekdays	Weekends
CO	11.60	11.15
$VOC_{tailpipe}$	1.13	1.06
VOC_{evap}	0.86	0.82
NO_x (as N)	0.75	0.72
SO_2	0.09	0.08
PM	0.013	0.012
CO_2	411.56	373.55
N_2O	0.031	0.028
CH_4	0.211	0.199

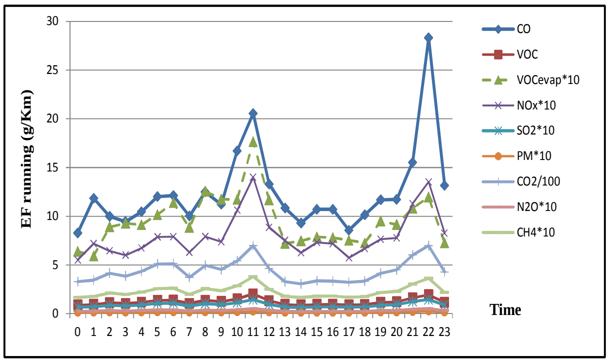
Table 3. Comparison of emission factors (g/km).

Pollutant	This study	Hanoi [11]	Vinh [12]
CO	11.38± 0.32	15.25	10.13
$VOC_{tailpipe}$	1.10 ± 0.05	1.70	0.70
VOC_{evap}	0.84 ± 0.03	0.91	0.64
NO_x (as N)	0.74 ± 0.02	0.96	0.54
SO_2	0.085 ± 0.007	0.12	0.07
PM	0.013 ± 0.001	0.02	0.01
CO_2	392.56 ± 26.88	545.78	340.54
N_2O	0.030± 0.002	0.04	0.03
CH_4	0.205 ± 0.008	0.32	0.13

As can be seen from table 2 that emission factors in weekdays are higher than those in weekends. The reason is that the average speed of the taxis in weekdays (10.8 ± 4.5 km/h) is lower than that in weekends (12.1 ± 4.4 km/h). The emission factor of a vehicle depends on a number of parameters including the technical specifications of the vehicle, the quality of fuel, driving behavior/cycle and meteorological conditions (ambient air temperature and humidity). For the same vehicle fleet, fuel and meteorological conditions, the emission factor and the speed have a negative relationship, meaning that, the former is increased when the latter is decreased, and vice versa. Daily variation of the emission factors and the speeds for taxis also reflects well this relationship as shown on figure 3. There are two high peaks of EFs on Figure 3, one is around 11 am, and the other is approx. 22 pm. The former case is related to the increase of traffic density during the rush hours, resulting in low speed, meaning that high EFs. However, low speed in the latter case is associated with other reason, which is called “cruising taxi”. At late night, as the demand for taxi is decreased, the taxi drivers have to cruise (driving in low speed) to find out passengers, resulting in high EFs. For other periods of the day (6 am to 10 am and 13 pm to 18 pm), the speed of the taxis is more stable and higher, leading to lower emission factors.



a)



b)

Figure 3. Daily variation of the emission factors (a) and the speeds (b).

The comparison of EFs obtained in this study with those conducted in Hanoi and Vinh with the same methodology is presented in table 3. As expected, the highest EF is observed in Hanoi, followed by Ha Long and the lowest is in Vinh. This can be explained by the difference in the number of starts up in the day. It is well known that most of CO and HC/VOC of a typical driving cycle occur in the first minute or two while the engine is cold. To start a cold engine the driver must operate it with a very rich air –fuel ratio (λ <1). This rich condition, combined with the cold walls of the combustion chamber, leads to very high CO and HC/VOC emissions [13]. The number of starts up of the engine is the highest in Hanoi (105 times/day) [14], followed by Ha Long (72 times/day) and the lowest is in Vinh (29 times/day) [12]. In addition, the percentage of taxis which are not met the emission standard of Euro II in Hanoi (5 %) [14] is higher than that in Ha Long (2 %) and Vinh (1 %) [12]. These are old vehicles resulting in the high emissions of air pollutants.

To the best of our knowledge, no measured data on the emission factors of taxis in Ha Long are found in the open literature to compare. However, according to our previous study [11], conducted for the taxi system in Hanoi with the same methodology, there was a relatively good agreement between the emission factors obtained by IVE and those done by the measurement (the chassis dynamometer method). This supposes that data gained for the Ha Long taxi system are reliable.

3.2. Co-benefit of climate

Table 4. Emission of CO_2 and respective reduction associated with the selected scenarios.

Item		Base state	Selected scenarios			
			CNG	LPG	Euro III	Euro IV
Emissions of CO_2 eq, ton/year	This study	24438	21271	21161	18158	17302
Reduction of CO_2 eq, ton/year		-	3168	3277	6280	7136
Reduction of CO_2 eq, %	This study	-	13.0	13.4	25.7	29.2
	Hanoi [11]	-	29.4	40.8	42.2	43.1
	Vinh [12]	-	15.0	17.5	24.9	29.5

The reduction of carbon dioxide equivalent (CO_2 eq) associated with the four selected scenarios is shown in table 4. All the scenarios lead to reductions in the emissions of CO_2 eq, from 13.0 % to 29.2 %, in which meeting the emission standards of Euro 4 is the best option.

According to the CCB standards (the Climate, Community and Biodiversity Standards), the average price of CO_2 eq in the voluntary carbon market in 2011 is 4.7 USD/ton CO_2 eq [15]. Thus, the amount of money obtained from selling carbon credits associated with CO_2 eq reduced in the selected scenarios of CNG, LPG, Euro III and Euro IV is 14889, 15402, 29515 and 33540 USD/year, respectively.

Emission factor of CO_2 on the basis of electricity generation in 2010 is 432 g CO_2 /kWh [16]. Therefore, the yearly reductions of CO_2 eq in the selected scenarios of CNG, LPG, Euro III and Euro IV are equivalent to 7.33, 7.59, 14.54 and 16.52 million kWh respectively. The consumption of electricity of Ha Long city is 37 million kWh/month [17]. It means that, the yearly reduction of CO_2 eq in the best scenario is equal to the amount of electricity that is enough for the consumption of Ha Long for about two weeks.

It can be seen from Table 4 that, with the same scenario, the reduction of CO_2 eq in Hanoi is much higher than that in Ha long and Vinh. In other words, Hanoi has a higher potential of co-benefit of climate than those of Ha Long and Vinh. The reason is that the emission factor of the base state in Hanoi is significantly higher in the comparison with those in Ha Long and Vinh.

3.3. Co-benefit of air quality

Co-benefit of air quality is presented in table 5.

Table 5. EFs and respective reduction of selected air pollutants for the scenarios.

Pollutants		CO	VOC	NO_x (as N)	SO_2	PM
Scenario	EF of base state	11.37	1.10	0.84	0.74	0.082
CNG	EF (g/km)	8.56	0.03	0.56	0.75	0.001
	Reduction, %	-24.7	-69.5	-4.8	-99.0	-93.2
LPG	EF (g/km)	8.75	0.24	0.69	0.91	0.001
	Reduction, %	-23.0	-52.2	22.8	-99.0	-93.0
Euro III	EF (g/km)	4.67	0.14	0.69	0.28	0.042
	Reduction, %	-58.9	-57.2	-62.5	-48.8	-62.6
Euro IV	EF (g/km)	1.43	0.08	0.66	0.20	0.007
	Reduction, %	-87.4	-61.7	-72.8	-90.9	-63.3
Note: Minus (-): reduced; $VOC = VOC_{tailpipe} + VOC_{evap}$						

It can be seen from table 5 that the four selected scenarios bring to substantial reductions in the emissions of air pollutants, meaning that, the improvement of air quality. For fuel switching, on the basis of air quality enhancement, CNG is better than LPG. However, for all selected scenarios, in general, meeting the emission standards of Euro 4 is the best option. It is nothing strange as the tightening of the emission standard is an integrated approach, in which, different measures including the improvement of vehicle (engine) quality, the installation of air pollution control equipment and the enhancement of fuel quality can be applied.

The exception is NOx in the scenario of LPG, in which, the emission factor is increased (+22.8 %) instead of decreasing. This is caused by the higher octane number of LPG which results in higher compression ratio. LPG has high octane rating 110+ that allows compression ratio to be high up to 15:1, which is in the range of 8:1 to 9.5:1 for gasoline engines [18]. Therefore, the temperature of combustion when using LPG is higher leading to higher emission of NOx as thermal NO is increased [13].

4. CONCLUSIONS

This study determined the emission factors of eight air pollutants namely CO, VOC, NO_x, SO_2, PM, CO_2, N_2O and CH_4 for the base state of Ha Long taxi system. The study also quantified the co-benefits of climate and air quality for this system associated with the four selected air pollution control scenarios. It is found that the switching from gasoline to either CNG or LPG as well as the tightening of emission standards to either Euro 3 or Euro 4 significantly contribute to the mitigation of climate change and the improvement of air quality. Data obtained in this study can be used as scientific basis for air pollution control of public transport system in particular and for air quality management in Ha Long in general.

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TÓM TẮT

ĐỒNG LỢI ÍCH VỀ KHÍ HẬU VÀ CHẤT LƯỢNG KHÔNG KHÍ THU ĐƯỢC KHI NÂNG CẤP HỆ THỐNG TAXI Ở THÀNH PHỐ HẠ LONG, TỈNH QUẢNG NINH

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Đã nghiên cứu tiềm năng đồng lợi ích thu được khi nâng cấp hệ thống taxi ở thành phố Hạ Long, tỉnh Quảng Ninh. Ba vùng và chín tuyến đường ở nội thành Hạ Long đã được chọn làm khu vực nghiên cứu. Thông tin về tình trạng kỹ thuật của xe taxi được thu thập qua 130 phiếu điều tra. Lưu lượng xe taxi trên 9 tuyến đường được xác định bằng phương pháp đếm xe. Thông tin tức thời về hành vi lái của xe taxi được xác định nhờ thiết bị GPS. Toàn bộ số liệu này đã được xử lý để làm dữ liệu đầu vào chạy mô hình IVE ứng với trạng thái nền và 4 kịch bản kiểm soát ô nhiễm không khí. Hệ số phát thải các chất ô nhiễm không khí của hệ thống taxi ở Hạ Long ứng với các trường hợp trên đã được xác định. Đồng lợi ích đối với khí hậu và chất lượng không khí đã được định lượng.

Từ khóa: đồng lợi ích, Hạ Long, mô hình IVE, taxi, chất lượng không khí, khí hậu, hệ số phát thải.