POTENTIALITY OF CO-BENEFITS OF CLIMATE AND AIR QUALITY IN FUEL SWITCHING FOR HANOI BUS SYSTEM

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ABSTRACT

Potentiality of co-benefits of climate and air quality in fuel switching from diesel to CNG (compressed natural gas) or LPG (liquefied petroleum gas) for Hanoi bus system was studied. Three areas and two bus routes in Hanoi were selected for conducting this study. Information of technical conditions of the bus system was collected by 100 questionnaires at 5 bus stations in Hanoi. Traffic flow was determined by vehicle counting in 9 different roads/streets. Real-time information on driving behavior of 2 bus routes was obtained by GPS. All data collected were processed to generate input files to run IVE model (international vehicle emission model) with base state and 4 scenarios. Emission factors (EFs) of Hanoi bus system and the reduction of CO_2 equivalent for each scenario were determined. Results indicate that fuel switching from diesel to CNG obtains the better improvement of air quality while changing from diesel to LPG achieves better contribution to climate change mitigation. At base state, EFs of CO, VOC, NO_x, SO_2, PM, CO_2 and N_2O for Hanoi bus system are in the same range with those in other cities having the similar traffic conditions in the world.

1. INTRODUCTION

Bus system in Hanoi has been being significantly developed for last years. The fleet of buses was risen nearly 2.5 times from 2001 to 2009, and this trend is expected to be continued. It plays an increasing and important role in transporting passengers. The number of bus passengers in the city was increased sharply from 3 million in 1992 to 329 million of participations in 2006 [1]. However, bus system also has been causing air pollution problem in Hanoi. According to the National State of Environment 2007 [2], traffic is the biggest air polluter in cities of Vietnam including Hanoi. Diesel–fired busses are high emitters of particulate matter, especially black carbon particles, and range of other toxic gases some of which (NO_x, HC) form ground level ozone. Black carbon particles (BC) and ground ozone are short-lived climate forcers which contribute significantly to climate change. Reduction of the emission from public buses in Hanoi will bring in benefits for both air quality and climate – co-benefit.

“Co-benefits” refers to multiple benefits in different fields resulting from one policy, strategy, or action plan. Co-beneficial approaches to climate change mitigation are those that also promote positive outcomes in other areas such as concerns relating to the environment (e.g., air quality management, health, agriculture, forestry, and biodiversity), energy (e.g., renewable energy, alternative fuels, and energy efficiency) and economics (e.g., long-term economic sustainability, industrial competitiveness, income distribution) [3]. Co-benefits approach is being smart about climate change mitigation because they help projects link with the community, share costs, eliminate hesitations and satisfy political issues. This method provides a list of potential impacts and predicts their quantity from a policy/project on local environment and global climate so it should be considered and included in any policies, plans, and decisions to determine their effects to climate change.

Reduction of the emission from public buses in Hanoi can be obtained by different approaches. This paper presents the approach of switching to cleaner fuels being CNG and LPG.

2. METHODOLOGY

Data on information of technical conditions, traffic flow and real-time information on driving behavior of buses were collected and analyzed to generate input files for International vehicle emission (IVE) model. Based on output file of the model, the emission factors (EFs) of Hanoi bus system and the amount of CO_2 equivalent were determined.

2.1. IVE model

IVE model was developed by the US Environmental Protection Agency (US EPA) and Office of International Affairs. This model is based on the success of the previous models including MOBILE 6, EMFAC 2007, and COPERT IV [4]. The model is used to estimate the quantities of air pollutants, greenhouse gases, and toxics emitting from vehicles. It was designed specifically to be able to meet flexible needs of developing countries in an effort to determine gas emissions from mobile sources.

Input files of IVE model include 3 data files being Location, Fleet and Base adjustment. In this study, due to limitations of time and equipment, only Location and Fleet files were used to determine emissions of Hanoi bus system.

2.2. Description of the study

Steps of conducting the study are presented in Figure 1.

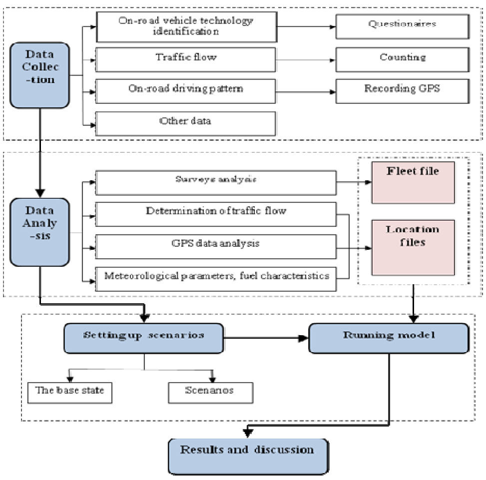

Figure 1. Framework of methodology

2.2.1. Study area

The study was focused on old Hanoi (before the expansion in 2008) only. Based on the requirements of the model, previous studies and actual conditions, three areas of the city including upper income (Area A), lower income (Area C), and commercial area (Area B) were chosen. In each area, three roads representing for three groups being highways (Group 1), arterials (Group 2), and residential roads (Group 3) were selected. They are Nguyen Van Cu, Giai Phong, and Thang Long Highway (Group 1); Nguyen Thai Hoc, Chua Boc, and Pham Hung (Group 2); Hang Voi, Nguyen Cong Tru, and Ham Nghi (Group 3). Two bus routes reflecting the scope of the study were also selected to be route 18 and route 30. All areas, roads and bus routes are shown on the Figure 2 and 3.

2.2.2. Data collection

Different data including traffic flow, technical identification of buses, driving pattern, fuel characteristics, and meteorological parameters were collected as follows:

Traffic flow

Traffic flow was obtained by counting the number of buses in each of the nine roads in three time periods (7 am – 9 am, 10 am – 11 am, and 1 pm – 3 pm) in a number of days from December 2010 to April 2011. Counting was carried out every 15 minutes with following 10 minutes off.

Figure 2. Areas and bus routes of the study

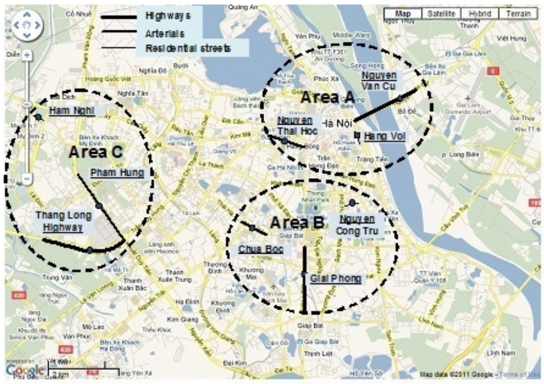

Figure 3. Representative roads

On-road vehicle technical identification

Questionnaires were used to collect information about vehicle flow (vehicle type, registration number, engine size, kilometer traveled, exhaust control devices, maintenance programs, time of operation) at the bus stations in Hanoi which are My Dinh Station, Kim Ma Station, South Station, Luong Yen Station and Kim Nguu Station. According to Vietnam Register, 1020 buses have been registered in Hanoi until 2009. So the corresponding sample size is approximately 100 samples [1]. Therefore, total of 100 questionnaires were used for survey.

On-road driving pattern

Information related to the operation of buses such as speed, location, and time break between engine starts-up was recorded by global positioning system (GPS). Two bus routes (18 and 30) were recorded on weekdays and weekends with GlobalSat DG-100 device which was on the buses during their working time from 5am to 9pm in days of January 2011.

Other data

Other data include fuel characteristics, meteorological parameters (temperature, humidity) and altitude of Hanoi. The characteristics of diesel fuel were collected from Petrolimex Hanoi while the other data were taken from the meteorological website www.climatetemp.info

2.2.3. Data analysis

This step was to build up two input files for the model.

Analysis of the surveys

The 100 questionnaires were summarized to figure out technological state of bus flow including type of fuel, gross vehicle weight rating (GVWR), air/fuel control, exhaust control, and age. Following these, classification of technological characteristics of buses as percentage was determined.

Determination of traffic flow

Results of counting buses on each road were calculated to determine the average traffic flow (vehicle/hour). Because there were 38 bus routes traveling on nine selected roads while the total number of bus routes in Hanoi is 67, the average traffic flow was multiplied by 67/38 to reflect the whole bus system.

Analysis of GPS data

Two very important parameters, vehicle specific power (VSP) and engine stress are set up to characterize vehicle-driving patterns in IVE model through GPS data.

VSP is defined as the power per unit mass to overcome road grade, rolling and aerodynamic resistance, and inertial acceleration [5]. Equation 1 is the initial equation for VSP [4].

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

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

Engine stress was shown to correlate best to vehicle power load requirements over the past 20 seconds of operation (from t = -5 sec to t = -25 sec) and implied engine revolutions per minute (RPM). Engine stress is calculated using Equation 2 [4].

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

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

$$RPM_{index} = Velocity_{t=0}/SpeedDivider \quad (unitless)$$

Analysis of start-up state

The term engine soak is defined as the duration of time in which the engine of the vehicle is not operating before starting again [4]. There are ten groups of engine soaks in the model.

Meteorological parameters and fuel characteristics

This study was conducted in the period when the buses did not use air conditioners, so the value of temperature and relative humidity were averaged from those parameters of six months from November to April. Calculations showed that the average temperature is 20°C and the average relative humidity is 71%. According to the standards of diesel oil of Petrolimex Hanoi, sulfur content limit is 0.05 mg/kg.

2.2.4 Setting up scenarios and running the model

To meet the purposes of this study, 5 options were defined to run on IVE model.

- The base state: presents conditions of Hanoi bus system at the time of the research.
- Scenario 1: 50% of existing buses of Hanoi is switched to use CNG (50% CNG)
- Scenario 2: 100% of existing buses of Hanoi is switched to use CNG (100% CNG)
- Scenario 3: 50% of existing buses of Hanoi is switched to use LPG (50% LPG)
- Scenario 4: 100% of existing buses of Hanoi is switched to use LPG (100% LPG)

It is assumed that the bus population and driving behavior in the four scenarios chosen are the same as the base state.

In each run, 4 Location files were set up from data of buses route 18 and route 30 in weekdays and weekends. Fleet file obtained from the analysis of surveys was used for all Location files. Output files of IVE model show the emission mass of pollutants per day or hour. In IVE model, pollutants are classified in three groups: criteria, toxics, and global warming. This study focused on groups 1 and 3.

2.2.5. Computation of results

Calculations were done to get the values of EFs and CO_2 equivalent.

Determination of emission factors

According to US EPA: Emission factors (EFs) are usually expressed as the weight of pollutant emitted divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant [6].

Using output data, emission factors can be calculated for every available hour. Comparison of EFs between each scenario and the base state was conducted to bring out impacts on air quality.

$$EF_{running} = \frac{M}{VKT} \text{ (g/km) and } EF_{start} = \frac{M}{N} \text{ (g/start)} \quad (3)$$

where: M – emission mass of the pollutant; VKT – vehicle kilometer traveled; N – number of start-ups.

Assessment of co-benefit of climate

Co-benefit of climate was analyzed via the value of CO_2 equivalent (CO_2 eq). This is a measure used to evaluate effects of emissions of pollutants to climate change.

$$CO_2(e) = \sum_{V,i} A_v * N_v * EF_{V,i} * P_i \quad (4)$$

where: N_v are the populations, A_V are average activity (km per year per vehicle) of vehicle type V (buses), $EF_{V,i}$ is the emission factor for emissions species I, averaged for vehicles of type V, P_i is the global warming or cooling potential of that species with respect to the reference species (CO_2) which is called the global warming potential (GWP).

Table 1. GPWs of pollutants

Pollutants	GWPs		Remark
	20 years	100 years	
CO_2	1	1	
CH_4	72	25	Fuglestvedt et al. (2009), indirect effects included
N_2O	289	298	IPCC, FAR 2007
NO_x	43	-28	Naik et al. (2005), values for tropics
SO_2	-57	-16	Value of sulfate for China and Siberi (Koch et al., 2007). Effects on clouds not considered
VOC	14	4.5	Collins et al. (2002)
CO	6	2	Derwent et al. (2001)
Hydro fluorocarbon (HFC)	12,000	14,800	IPCC, FAR 2007
Sulfur Hexafluoride (SF_6)	16,300	22,800	IPCC, FAR 2007
Black Carbon (BC)	2200	680	Forster and Ramaswamy, 2007
Organic Carbon (OC)	-240	-69	Fuglestvedt et al. (2009)
Sunfate (SO_4^{2-})	-40	140	Fuglestvedt et al. (2009)

Source: [1]

BC and OC can be estimated based on fuel and PM emission of IVE output. Kim Oanh et al. (2010) determined BC and OC fractions in PM from diesel are 0.46 and 0.2, respectively [1]. Assuming that Y was the component of vehicles using diesel (in this study, Y = 100%), emissions of BC and OC can be calculated through PM emission taken from IVE model (M) by following equations:

$$BC = 0.46 \times Y \times M \text{ and } OC = 0.2 \times Y \times M . \quad (5)$$

3. RESULTS AND DISCUSSIONS

3.1 Emission factors of Hanoi bus system

EFs of Hanoi bus system for start-up stage (EFs start) and running stage (EFs running) in the base state are shown in Table 2.

Table 2. Emission factors of Hanoi bus system

Pollutants	EF Start (g/start)	EFs running (g/km)		
		EFs in weekdays	EFs in weekends	Average of EFs
CO	0.20	3.63	3.40	3.47 ± 0.58
VOC	0.02	0.87	0.81	0.83 ± 0.15
$VOC_{evap.}$	0	0	0	0
NO_x (calculated as N)	0.71	28.17	26.35	26.91 ± 4.53
SO_2	0.00	0.13	0.12	0.12 ± 0.019
PM	2.96	8.05	7.54	7.69 ± 1.28
CO_2	15.44	1253.68	1181.28	1202.38 ± 191.56
N_2O	0.00	0.01	0.01	0.01 ± 0.0015
CH_4	0	0	0	0

3.1.1.EFs in weekdays and EFs in weekends

Traffic activities vary from weekdays to weekends leading to the variation of EFs. The final EFs were averaged by those in two different time periods of the week. All EFs in weekdays are higher than those in weekends and this reflects real traffic conditions in Hanoi. The most differential value is 7.5% which belongs to EFs of VOC while the smallest difference is of SO_2, CO_2, and N_2O at 6.1%. Detail data are shown in Table 2.

3.1.2. Temporal distribution of EFs

Ranges of EFs from 5am to 9pm in a working day are: CO (4 – 6.4 g/km), VOC (0.9 – 1.6 g/km), NO_x (31 – 49.5 g/km), SO_2 (0.1 – 0.2 g/km), PM (8.8 – 14.1 g/km), CO_2 (1609 – 2056 g/km), and N_2O (0.01 – 0.02 g/km).

Figure 4 shows that the highest EFs are at afternoon rush hours (5 pm), which is reasonable as this is the most crowded traffic time. Also, EFs are very sharp at 5 am when a working day is started. Another remarkable point is at around 11am and it may be due to the end of morning shift for most offices and schools.

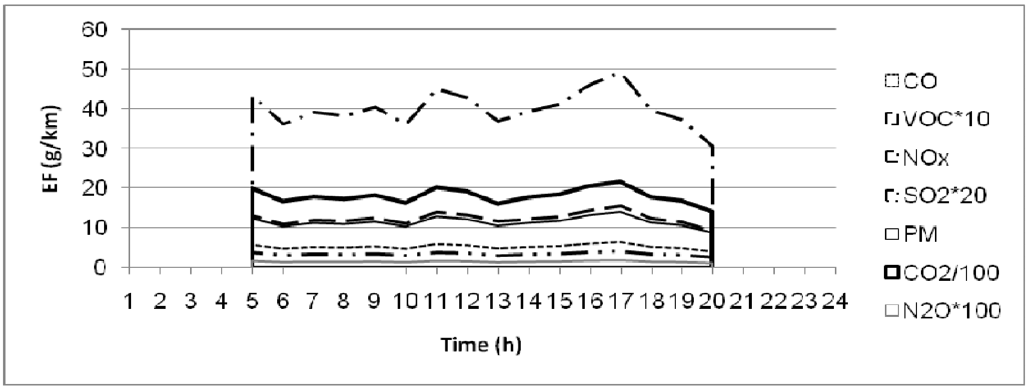

Figure 4. EFs distribution of CO, VOC, NO_x, SO_2, PM, and CO_2 in 24 h

Comparison of EFs

Comparing the results (EFs running) of this study with other ones, also conducted in Hanoi as can be seen in Table 3, indicates that there are certain differences among them. However, the differences can be explained by the diversity in on-road transport operation in Hanoi as well as the application of different methodologies.

Table 3. Comparison of EFs (g/km) of this study with others ones in Hanoi

Pollutants	This study	Trang, 2011 [1]	Hung, 2010 [7]
CO	3.47	5.15	3.10
NO_x	26.91	12.65	7.60
SO_2	0.12	0.09	0.64
PM	7.69	1.55	1.50

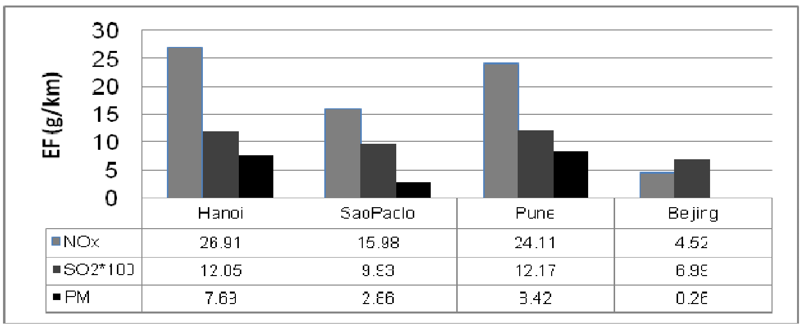

Figure 5. EFs of buses in four cities using IVE model

Figure 5 illustrates EFs of NO_x, SO_2 and PM for buses obtained by the applications of IVE model in 4 different cities being Hanoi, Sao Paolo (Brazil) and Pune (India) and Beijing (China). All buses in Hanoi, Sao Paolo and Pune use diesel oil. Other transport conditions of these cities can also be considered to be the same. As anticipated, the EFs of bus system in Hanoi, Sao Paolo and Pune are in the same range. Buses in Beijing, however, use different fuels including diesel, petrol, CNG and LPG in which CNG and LPG make up a big share. These results in lower EFs of bus system in Beijing in the comparison with other cities mentioned including Hanoi. This is also a good example proving the efficiency of fuel switching for buses in reducing the emission of air pollutants.

3.2 Co-benefits of air quality and climate

3.2.1. Benefit of air quality

Impacts of fuel switching of Hanoi bus system to the air quality are assessed by the variations of emission factors between different scenarios proposed and the base state as shown in Table 4.

Table 4. EFs (g/km) of Hanoi bus system in different scenarios

Pollutants	Base state	Scenario 1	Scenario2	Scenario3	Scenario4
CO	3.47	42.35	81.14	42.35	81.14
VOC	0.83	0.71	0.58	2.85	4.87
$VOC_{evap.}$	0.0000	0.0023	0.0045	0.0023	0.0045
NO_x	26.91	16.00	4.53	16.42	5.38
SO_2	0.12	0.06	0.00	0.06	0.00
PM	7.69	4.58	0.00	4.58	0.00
CO_2	1202.38	883.41	544.48	903.83	585.31
N_2O	0.01	0.01	0.01	0.01	0.01
CH_4	0.00	5.05	7.53	0.34	0.50

Table 5. The variations of EFs in the comparison with the base state

Pollutants	Scenario 1	Scenario2	Scenario3	Scenario 4
VOC	-14.10%	-29.46%	244.56%	487.85%
NO_x	-40.54%	-83.17%	-38.96%	-80.01%
SO_2	-48.45%	-98.56%	-48.45%	-98.56%
PM	-40.44%	-99.97%	-40.42%	-99.95%
CO_2	-26.53%	-54.72%	-24.83%	-51.32%
N_2O	-12.52%	-29.46%	-12.52%	-29.46%

It can be seen from Table 5 that all proposed scenarios produce two pollutants ($VOC_{evap.}$ and CH_4) that are not occurred in the base state. In scenarios 1 and 2, the EFs of most pollutants are considerably decreased. Similarly, in scenarios 3 and 4, the EFs of most pollutants are significantly reduced with the exception of VOC. CO is also an exception as its EFs are increased in all scenarios in the comparison with the base state. However, CO is not a main air pollutant emitted by buses so the improvement of the air quality is predominant.

With regard to buses, the most concerning pollutants are SO_2, NO_x, and PM. Figure 6 describes their reductions in the comparison with the base state. Scenarios 2 and 4 result in the extraordinary reduction of emissions of SO_2, PM, and NO_x at about 99%, 100%, 80%, respectively. Meanwhile, other scenarios bring in less than a half of reduction. In short, scenario 2 provides the most effective improvement on the air quality.

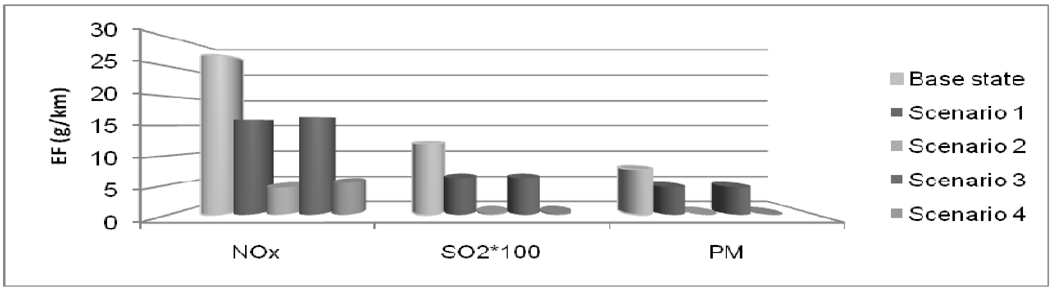

Figure 6. Emission reductions of NO_x, SO_2 and PM

3.2.2. Benefit of climate

The reduction of greenhouse gases emissions as CO_2 eq for the four proposed scenarios is presented in Table 6.

Table 6. Amount CO_2 eq in the base state and scenarios

	Base state	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Emissions of CO_2 eq (tonne/year)	147.045	99.062	26.319	95.085	20.879
Reductions of CO_2 eq (tonne/year)		47.983	120.727	51.961	126.167

Scenario 4 decreases the biggest amount of CO_2 eq, at 85.8%. The second one is scenario 2 with a reduction of 82.1%. The reductions of two other ones are less.

These reductions of CO_2 eq can be converted into the amount of electricity generated in Vietnam. According to International Energy Agency (IEA), the average carbon dioxide emission to produce 1 kWh in Vietnam was 413 g/kWh (in 2008) [8]. Electricity consumption each day of Hanoi was estimated about 30 million kWh (in May/2010), according to Vietnam Green Building Council. Thus, the quantities of CO_2 eq emission reductions of the four scenarios proposed are equivalent to CO_2 emissions to produce 116, 292, 125 and 305 million kWh, respectively. These numbers are in the range of 4 and 10 times of the power consumption per day in Hanoi. In summary, the change from 100% diesel to 100% LPG is the best option for climate change mitigation.

4. CONCLUSION

Emission factors of selected air pollutants of Hanoi bus system using diesel fuel are determined. These data can be applied to estimate the emission of the air pollutants which are very important information for the air quality management in Hanoi. Co-benefits analysis shows that fuel switching from diesel oil to CNG and/or LPG will improve significantly the air quality of Hanoi and reduce sharply the greenhouse gases emission of Hanoi bus system in parallel. The results of this study also indicate that co-benefits approach should be applied to evaluate projects and policies in terms of their impacts on climate.

The methodology used in this study to estimate the emission factors of buses and analyze co-benefits of air quality and climate in Hanoi can be expanded to other types of vehicles in any other location of Vietnam.

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TÓM TẮT

ĐÁNH GIÁ TIỀM NĂNG ĐỒNG LỢI ÍCH ĐỐI VỚI KHÍ HẬU VÀ CHẤT LƯỢNG KHÔNG KHÍ KHI CHUYỂN ĐỔI NHIÊN LIỆU CHO HỆ THỐNG XE BUÝT HÀ NỘI

Đã tiến hành nghiên cứu đánh giá tiềm năng đồng lợi ích khi chuyển đổi nhiên liệu cho hệ thống xe buýt Hà Nội, từ diesel sang CNG hoặc LPG. Ba khu vực và hai tuyến xe buýt ở Hà Nội đã được chọn để thực hiện nghiên cứu này. Dữ liệu về tình trạng kỹ thuật của xe buýt được thu thập qua 100 phiếu điều tra tại 5 bến xe buýt của Hà Nội. Lưu lượng xe được xác định thông qua đếm xe trên 9 tuyến đường khác nhau. Các thông số về hoạt động tức thời của 2 tuyến xe buýt thu được nhờ thiết bị GPS. Toàn bộ số liệu trên đã được tổng hợp để làm dữ liệu đầu vào để chạy mô hình IVE (mô hình xác định phát thải của phương tiện giao thông) ứng với trạng thái nền và 4 phương án chuyển đổi. Hệ số phát thải và mức giảm CO_2 tương đương ứng với các phương án chuyển đổi đã được xác định. Kết quả cho thấy rằng, việc chuyển đổi nhiên liệu từ diesel sang CNG đóng góp nhiều hơn cho việc cải thiện chất lượng không khí, trong khi chuyển đổi từ diesel sang LPG đóng góp nhiều hơn vào việc giảm nhẹ sự biến đổi khí hậu. Ở trạng thái nền, hệ số phát thải đối với CO, VOC, NO_x, SO_2, PM, CO_2 và N_2O của xe buýt Hà Nội nằm trong cùng một cấp độ so với các thành phố khác trên thế giới có cùng điều kiện giao thông.

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