Original Article

Co-Benefits of Climate Change Mitigation for Public Transport in Different Cities of Vietnam

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Abstract: Potentiality of co-benefits for public transport at cities of different grades in Vietnam namely Ho Chi Minh city (special city), Da Nang (centrally-run grade I city) and Vinh (grade I city under the province) in 2013 was studied. Taxis in Da Nang and Vinh, and buses in Ho Chi Minh City were selected for the study. A same methodology was used for all cities. In each city, three areas and nine routes in inner city were selected for conducting this study. Information on the technical conditions of vehicles was collected by questionnaires. Traffic volume was determined by vehicle counting. The real–world driving data of vehicles were recorded by GPS technology. All collected data were processed to generate input files to run IVE model associated with base state and three proposed scenarios of climate change mitigation. Emission factors (EF) of air pollutants for these transport means were determined. Co-benefits of climate, air quality and health for the scenarios in three cities were assessed. The obtained results in this study can be used as a scientific basis for integrated air quality management in the cities in general and for air pollution control of public transport in particular.

Keywords: Co-benefits, public transport, emission factor, IVE model, Vietnam.

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1. Introduction

Road transport was reported being the most important source of air pollution in urban areas [1, 2]. The major air pollutants come from gasoline and diesel engines including carbon monoxide, nitrogen oxides, non-combustible hydrocarbons, and particulate matter that also were indicated as greenhouse gases causing climate change (GHGs). Although the emission control technologies for motorcycles cars are enhanced gradually, the number of vehicles keeps raising significantly. Beside motorcycles, other on-road vehicle means, such as bus and taxi, have also increased in recent years in many big cities [1]. The number of taxi in Da Nang in 2007 was 424 but in 2012, the data were double higher than the number in 2007 while quantity of Mai Linh taxi was 100 and 500 in 2007 and 2012, respectively (DOT of Da Nang, 2013; Mai Linh Group, 2009). On the other hand, the number of bus in Ho Chi Minh City increased during 2004 - 2008 but decreased from 2008 to 2012 because a lot of old buses was removed (CCPT, 2012). Because of increasing vehicle quantity, air quality becomes worse and worse. Air pollution is considered being the biggest environmental threat to human health in Vietnam, even more serious than traffic accidents. Heart diseases and stroke are the most common causes of premature mortality associated with air pollution, accounting for 80% of early deaths; followed by lung diseases and lung cancer [3]. However, there is no detailed analysis of emission of public transport fleets as well as the health benefits of climate change mitigation according to various emission control strategies. Hence, to assess the effectiveness of these measures, this study is highly required.

2. Methodology

2.1. Research design

The methodology of this study is presented in Figure 1.

The primary data collection of taxis was conducted in Vinh and Da Nang while buses were studied in Ho Chi Minh City (HCMC) following the IVE method which consist of questionnaire survey, GPS recording and vehicle flow monitoring [4]. The secondary data included the vehicle population, fuel characteristics, engine technology, meteorology, and on-road driving patterns (running distance and number of starts). All primary and secondary data were used to generate the input files for conducting relevant EFs for each study area. Three road types (highways, arterial and residential roads), that were selected to run through three zones representing each city including higher income (zone A), commercial (zone B) and lower income (zone C). The selected roads for each study area are shown in Table 1.

2.2. Data collection and processing

Parking lot questionnaire survey

The questionnaire survey was carried out to identify the technology type shares of buses in HCMC, taxis in Da Nang and Vinh. The sample size was determined to provide a 90% confidence estimate following the method illustrated in Taro Yamane. The numbers of vehicles subjected for survey were 2953 buses in HCMC, 923 taxis in Da Nang and 761 taxis in Vinh. The information of model year, weight, fuel, engine, exhaust control, age, daily traveled distance and traveled total distance were collected to better determine the vehicle technologies.

Vehicle Kilometers Traveled (VKT) estimation

The regression analysis of the accumulated odometer readings of 100 surveyed buses in HCMC, 120 surveyed taxis in Da Nang and 100 surveyed taxis in Vinh (O_v) in km and the vehicle age in years was conducted. The O_v value that is presented in Equation (1) was calculated using the average age of vehicle fleet obtained from the survey to estimate the average annual usage of a vehicle (Tv), km/year.

$$T_v = O_{v,a+0.5} - O_{v,a-0.5} \qquad (1)$$

Driving activities and Vehicle Specific Power (VSP) distribution

The vehicle driving data were recorded every second using Garmin GPSmap76CSx and Garmin eTrex Vista HCx attached on the vehicle while it was running on different roads in HCMC, Da Nang and Vinh. The recorded data included information of longitude, latitude, altitude, and speed. GPS monitoring for bus was conducted in the period of 16 hours that is daily operation time of bus, while for taxi, GPS data was produced 24/24 hours. The recorded data were used to determine the driving pattern in the form of VSP developed by Jimenez's method (1999) [5]. There are 20 VSP groups for each three engine stress modes (low, medium and high) and 60 bins for each monitored vehicle type per hour. These data are a required input for the IVE model [4]. The GPS data were also used to identify the start pattern that consists of number of start and the engine soak time that is an important determinant of the vehicle exhaust emission. A high emission is generated during a cold start, i.e., a start when the engine has completely been cooled off.

Vehicle flow monitoring

Vehicle counting was done manually at nine selected roads, one location for each road in HCMC, Da Nang and Vinh, for three periods in a monitoring day (07:00-09:00 and 17:00-19:00 to cover rush hours, and 10:00-11:00 and 13:00-15:00 to cover normal hours. Therefore, for every selected road, a total of 180 minutes of vehicle counting was recorded (continuously counting over 15 minutes followed by a 10-minute break).

Secondary data collection

Hourly temperature and humidity in Hanoi were given from the Weather Underground website www.wunderground.com. The data on fuel characteristics were extracted from the information by the standards of Petrolimex and the Vietnam National Petroleum Corporation (VNPC). All the data were used in the location input file of IVE.

2.3. IVE modeling

Large number of default vehicle technologies, which are identified by engine technology, vehicle weight, mileage, fuel used, air/fuel control and exhaust control devices are incorporated in IVE model.

All the collected primary data were processed to prepare the two input files (Fleet Input file and Location Input file). The third input file (Base adjustment file) is an optional file because this only generates when the local EF data are available. For the output of fifteen default pollutants in IVE, nine pollutants were analyzed in this study which included pollutants affecting air quality (CO, VOC, VOC_{evap}, NO_x, SO_x, PM_{10}) and GHGs (CO_2, N_2O, CH_4).

With the hypothesis that early actions to improve the vehicle technologies can contribute to improve air quality, mitigation of climate change and protect the public health, faster intrusion scenario of fuel change and compliance with Euro IV were also examined according to the vehicle technology road map of Vietnam.

2.4. Emission reduction scenarios

The emission inventory (EI) for buses in HCMC, taxis in Da Nang and Vinh were produced for the base case of 2013. In addition, three scenarios with faster technology-intrusion scenario were conducted which assumed that 100% buses in HCMC, 100% taxis in Da Nang and Vinh using CNG (Scenario 1), LPG (Scenario 2) and comply with Euro IV (Scenario 3), respectively.
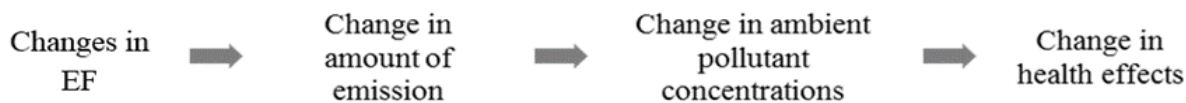
2.5. Co-benefit

Co-benefits of climate and air quality

Co-benefits of climate and air quality were calculated following the methodology, which is presented in detail in our previous studies [6-8].

Co-benefit of health

To evaluate health benefits related with the control scenarios of air pollution for public transport in three cities we assumed that the

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

people are exposed only to pollutants, which are emitted from public transport activities. In addition, in each city, all other factors are equal in all scenarios except the EF in each scenario. Co-benefit of health associated with the proposed scenarios are, therefore, estimated based on the changes in ambient air pollutant concentrations, that are converted into the changes in health effects, as illustrated above.

To calculate the concentrations of air pollutants at a location which relate to the emission of roadway we used the improved air pollutant dispersion model from roadway traffic of Régis et.al (2011) [9].

AirQ+ model was used to estimate the health effects. This model is proposed by World Health Organization for the assessment of 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 for pollutants not included in AirQ+ if relative risks (RRs) are available [10]. In which, the RRs are used based on the epidemiology study results of Vietnam and some other countries in Asia (Table 2).

3. Results and discussion

3.1. Emission factors of public transport in the cities

Average emission factors (EF) of public transport in weekdays (WDs) and weekends (WKs) for the base state are shown in Table 3.

Data collection			
Data of bus specifications	Traffic flow	Data of on-road driving pattern	Secondary data

Data analysis			
Survey analysis	Determination of traffic flow	GPS data analysis	Meteorological parameters, fuel characteristics

Setting up scenarios	
The base state	Scenarios

Running vehicle emission model (IVE model)	
EF of the state base	EF of scenarios

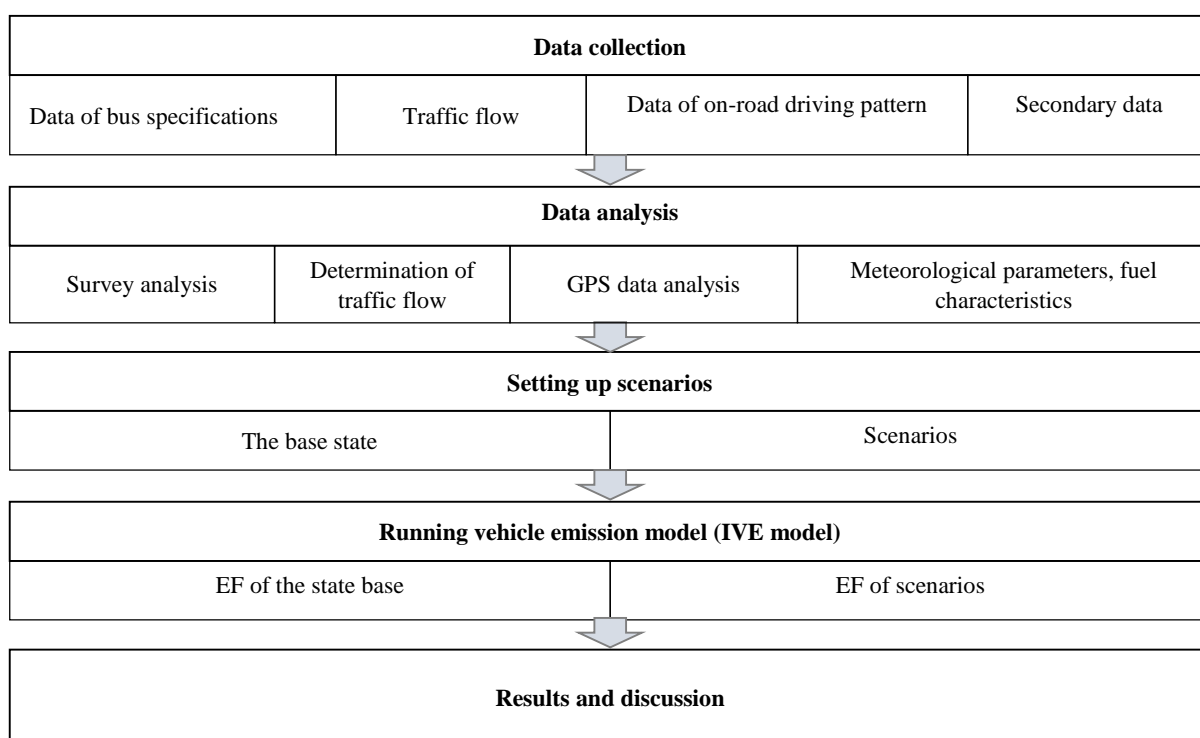| Results and discussion |
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Figure 1. Framework of methodology.

Table 1. Summary of selected roads for three study area

City	Zone	Highways	Arterial roads	Residental roads
Ho Chi Minh	A	Nguyen Van Linh	Nguyen Thi Thap	Le Van Luong
	B	Dong Tay Boulevard	Le Duan	Nguyen Thi Minh Khai
	C	Hanoi highway	Kha Vạn Can	Vo Van Ngan
Da Nang	A	Dien Bien Phu	Nguyen Tri Phuong	Ham Nghi
	B	2-9	Le Duan	Trieu Nu Vuong
	C	Ngu Hanh Son	Ho Xuan Huong	Ba Huyen Thanh Quan
Vinh	A	Lenin	Nguyen Sy Sach	Kim Dong
	B	Le Duan	Nguyen Van Troi	Cu Chinh Lan
	C	Quang Trung	Nguyen Thi Minh Khai	Dang Tat

Table 2. Relative risks for selected pollutants

Health outcomes	Relative risks (with increase of concentration is 10 $\mu g/m^3$)			Sources
	NO_x	SO_2	$PM_{2.5}$	
Hospital admissions for acute lower respiratory infections (ALRI) in young children	-	1.077	-	[11]
Mortality from all non-accidental causes	1.014	1.019	1.009	
Cardiovascular mortality	-	-	1.016	[12,13]
Respiratory mortality	-	-	1.022	
Acute conjunctivitis	1.06	-		[14]
Chronic conjunctivitis	1.10	-	-	

Note: the health risks associated with short-term exposure

Table 3. EF$_{running}$ of vehicles in the studied cities (g/km)

Pollutants	Taxi in Vinh				Taxi in Da Nang				Bus in Ho Chi Minh			
	Average		WKs	WDs	Average		WKs	WDs	Average		WKs	WDs
CO	10.13 ± 0.53	(11.38 ± 0.32)	9.86	10.4	14.64 ± 3.83	(15.25 ± 0.45)	12.69	16.6	3.13 ± 0.09	(3.47 ± 0.58)	3.06	3.19
VOC	0.70 ± 0.28	(1.10 ± 0.05)	0.56	0.85	1.04 ± 0.23	(1.70 ± 0.08)	0.93	1.16	0.68 ± 0.02	(0.83 ± 0.15)	0.67	0.7
NO_x (as N)	0.54 ± 0.22	(0.74 ± 0.02)	0.38	0.7	0.76 ± 0.21	(0.96 ± 0.13)	0.68	0.84	23.16 ± 0.44	(26.91 ± 4.53)	22.85	23.48
SO_2	0.07 ± 0.01	(0.085 ± 0.007)	0.06	0.08	0.07 ± 0.01	(0.115 ± 0.007)	0.07	0.08	0.11 ± 0.00	(0.12 ± 0.019)	0.11	0.11
PM	0.01 ± 0.00	(0.013 ± 0.001)	0.01	0.01	0.01 ± 0.01	(0.02 ± 0.00)	0.01	0.02	6.26 ± 0.16	(7.69 ± 1.28)	6.14	6.37
CO_2	340.54 ± 77.11	(392.56 ± 26.88)	284.9	396.17	351.97 ± 53.04	(545.78 ± 33.21)	312.81	391.13	1079 ± 24	(1202 ± 191)	1062	1097
N_2O	0.03 ± 0.01	(0.030 ± 0.002)	0.02	0.03	0.04 ± 0.01	(0.04 ± 0.00)	0.03	0.04	0.01 ± 0.00	(0.01 ± 0.0015)	0.01	0.01
CH_4	0.13 ± 0.04	(0.205 ± 0.008)	0.1	0.16	0.20 ± 0.06	(0.32 ± 0.01)	0.18	0.22	0.02 ± 0.00	0	0.02	0.02
Note	The values in ( ) are the EF of taxi in Quang Ninh [8]				The values in ( ) are the EF of taxi in Ha Noi [7]				The values in ( ) are the EF of bus in Ha Noi [6]			

It can be seen from Table 3 that all EFs in weekdays are higher than those in weekends reflecting real traffic conditions in big cities. In addition, the CO emission factor of vehicles using gasoline fuel is always higher than that using diesel fuel, even its load is higher. This result is similar with the other studies in Vietnam [6-8], and the study in [15]. For the same vehicle type (such as taxi), the emission factor of all pollutants in Da Nang city are higher than those in Vinh city. This can be explained by the fact that Da Nang is centrally-run grade I city so the vehicle density is higher, the taxi flow in Da Nang was 81 vehicles per hour while only 46 vehicles per hour were counted in Vinh.

3.2. Co-benefits of climate change mitigation

Benefits of air quality

Benefits of air quality for public transports in big cities are identified depend on changes of the EF in scenarios comparing with them in base state. Benefits of air quality are shown in Table 4.

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

CNG and LPG generally contain practically zero S (except trace amount in the odorant (mercaptan) added to gas for safety reasons), whereas DO contain a certain amount. That is why switching from DO to CNG or LPG can reduce the almost emission of SO_2, the SO_2 emission reducing efficiency can reach up to 98% in all scenarios related to switching fuel. In addition, these fuels have simpler molecules than DO then their combustion is more likely to be completed than DO, leading to lower VOC and PM emission. The results in Table 2 also shown that using CNG fuel can reduce NOx emission, around 3% and 98% for converting from gasoline and diesel fuel to CNG. These results are conformity to the other study results, which were presented in [6-8, 15]. 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 scenarios related to switching fuel (except cases converting from gasoline to LPG) can also be explainable. CH_4 is the major component of CNG and the second component of LPG but it is absent in 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 [15]. The results in Table 2 are conformity to the study of Abdullah Yasar et.al. [15].

On the other hand, when the public transports meet the EURO IV standards, their exhaust is strictly controlled/treated leading to lower emissions of all air pollutants.

Benefits of climate

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

The reduction of carbon dioxide equivalent (CO_2eq) associated with the three selected scenarios is shown in Table 5. All the scenarios lead to CO_2eq reductions from around 15% to 89%, in which complying with Euro IV is the best option. The obtained climate benefits of bus system are higher than the taxi system. This can be explained by the fact that the diesel combustion releases more pollutants than gasoline combustion, in which BC is a substance has 20-year GWP equal 4.470 [16].

Using the online greenhouse gas equivalencies calculator tool of US Environmental Protection Agency (EPA) we can see that 1 ton CO_2eq reduced is equivalent to greenhouse gas emissions from 0.211 passenger vehicles driven for one year, or 2.397 miles driven by an average passenger vehicle, or 0.371 tons of waste recycled instead of being landfilled; or equivalent to CO_2 emissions from 113 gallons of gasoline consumed, or 1067 Pounds of coal burned [17].

Benefits of health

In this study, we used $EF_{running}$, which is determined when the vehicle is running, so PM predominantly found in the fine fraction ($PM_{2.5}$) [18, 19]. $PM_{2.5}$, therefore, is used to estimate

benefits of health. 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 long-term exposure of $PM_{2.5}$, SO_2 and NO_x. These pollutants are normally used in studies about the effects of transport-related air pollutants on mortality and hospital admissions [20, 21]. The obtained health benefits are shown in Table 6.

The results of health impact assessment due to long-term exposure in Table 6 shows that the health benefits associated with reduction of $PM_{2.5}$, SO_2 and NO_x can be achieved when applying different emission control scenarios for public transport in the three cities. In which, the

health-benefit from the bus system is more significant than the taxi system. In addition, the health-benefit for the bus system is obtained from fuel switching scenario is higher than emission control standard tightening scenario. By contrast, for the taxi system, fuel switching scenario provides less health-benefit than Euro IV implementation scenario. This can be explained by the fact that switching from DO to CNG or LPG could bring higher emission reduction in comparison with switching from gasoline to CNG or LPG (Table 6). Besides, the health benefits of the taxi system in Da Nang that are achieved from these scenarios are quite similar to the taxi system in Vinh.

Table 4. Benefits of air quality for public transport in big cities (%)

Pollutants	Switching fuel						Meeting the emission standards EURO IV		
	Bus in Ho Chi Minh		Taxi in Da Nang		Taxi in Vinh		Bus in Ho Chi Minh	Taxi in Da Nang	Taxi in Vinh
	CNG	LPG	CNG	LPG	CNG	LPG			
CO	↑	↑	-30.46	-30.46	-20.25	-20.25	-88.71	-79.44	-86.36
VOC	-93.42	-44.59	-94.87	-57.99	-96.44	-70.37	-95.03	-88.91	-89.08
NO_x (as N)	-98.70	-98.45	-3.58	↑	-3.78	↑	-77.42	-63.02	-64.77
SO_x	-98.13	-98.13	-98.80	-98.80	-98.78	-98.78	-17.76	-24.83	-25.58
PM	-99.92	-99.84	-95.92	-91.85	-95.92	-91.84	-93.19	-62.75	-62.71
CO_2	-38.06	-33.42	-25.37	-16.35	-22.22	-18.36	-19.39	-19.30	-14.11
CH_4	↑	↑	↑	-35.00	↑	-38.46	-88.71	-90.00	-92.31
Note: Minus (-) is reduced; (↑) is not reduced									

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

Results in this study	Item	Base state	Scenarios		
			CNG	LPG	Euro IV
Bus in Ho Chi Minh	Emission of CO_2eq, ton/year	1231.09	145.33	132.35	173.47
	Reduction of CO_2eq, %		88.2	89.25	85.91
Taxi in Da Nang	Emission of CO_2eq, ton/year	27.41	22.53	22.33	17.50
	Reduction of CO_2eq, %		17.80	18.53	36.16
Taxi in Vinh	Emission of CO_2eq, ton/year	16.41	13.94	13.54	11.57
	Reduction of CO_2eq, %		15.03	17.52	29.51
Comparison with other studies					
Bus in Ha Noi [6]			82.1	85.8	
Taxi in Ha Noi [7]	Reduction of CO_2eq (%)		32.3	39.5	54.9
Taxi in Quang Ninh [8]			13.0	13.4	29.2

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

Results in this study	Health effects (Health indicators)	Health data (all ages)						
		Number of cases per year				Reduction (%)		
		Base state	CNG	LPG	Euro IV	CNG	LPG	Euro IV
Bus in HCMC	Hospital admissions for acute lower respiratory infections (ALRI) in young children	170	168	168	169	1.2	1.2	0.6
	Mortality from all non-accidental causes	189	153	153	154	19.0	19.0	18.5
	Cardiovascular mortality	143	134	134	135	6.3	6.3	5.6
	Respiratory mortality	190	179	179	180	5.8	5.8	5.3
	Acute conjunctivitis	225	114	114	139	49.3	49.3	38.2
	Chronic conjunctivitis	338	179	180	217	47.0	46.7	35.8
Taxi in Da Nang city	Hospital admissions for acute lower respiratory infections (ALRI) in young children	169	168	168	169	0.6	0.6	0.0
	Mortality from all non-accidental causes	154	154	154	153	0.0	0.0	0.6
	Cardiovascular mortality	134	134	134	134	0.0	0.0	0.0
	Respiratory mortality	179	179	179	179	0.0	0.0	0.0
	Acute conjunctivitis	116	116	116	114	0.0	0.0	1.7
	Chronic conjunctivitis	183	182	183	179	0.5	0.0	2.2
Taxi in Vinh city	Hospital admissions for acute lower respiratory infections (ALRI) in young children	169	168	168	169	0.6	0.6	0.0
	Mortality from all non-accidental causes	154	153	154	153	0.6	0.0	0.6
	Cardiovascular mortality	134	134	134	134	0.0	0.0	0.0
	Respiratory mortality	179	179	179	179	0.0	0.0	0.0
	Acute conjunctivitis	115	115	115	113	0.0	0.0	1.7
	Chronic conjunctivitis	181	181	181	178	0.0	0.0	1.7

Note: Estimating health effects is based population size of 100000 persons.

4. Conclusion

The study determines quantitatively the co-benefits of health, climate and air quality for the public transport system associated with the three control scenarios. It is found that the fuel switching from diesel to either CNG or LPG as well as the tightening of the emission standards to EURO IV significantly contribute to the mitigation of climate change, the improvement of air quality and the reduction of health effects. Of which, the fuel switching from diesel to CNG would obtain the highest benefits to either environment or health.

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