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Application of the AERMOD Model to Evaluate the Health Benefits Due to Air Pollution from the Public Transport Sector in Ha Noi, Viet Nam

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Abstract

Fine particulate matter ($PM_{2.5}$) mainly originates from combustion emissions on-road transportation. Exposure to $PM_{2.5}$ could be considered one of the primary causes of diseases such as heart attack, stroke, lung cancer, and chronic respiratory, which made it one of the most important co-benefits when evaluating the impact of GHG mitigation measures. This study quantifies the co-benefit of Ha Noi's modal shift from private to public means of transport, which are reduced air pollution and extended life expectancy, combining AERMOD model and benefit transfer method. Analytical results show that shifting from motorbike to electric train could be the most beneficial option in term of health co-benefit, compared to the usage of standard buses and BRTs.

Keywords

AERMOD Model, Air Pollution, Health Co-Benefit, Ha Noi

1. Introduction

An efficient and modern traffic system is an essential element for economic development. However, the unsynchronized development of a traffic system could lead to negative problems such as air pollution, congestion, and traffic accidents. This presented a problem with the traditional approach in transportation planning in developing countries. Building more roads and highways is an unsustainable approach in the context of responding to climate change. In the field of transportation, recent studies have been conducted on the issue of GHG mitigation, efficient energy usage, impacts on human health, saving travel time, reducing congestion, and air and noise pollution (Zusman & Romero, 2011).

The study of air quality has been carried out in many countries since the 60s-70s and has been obtained certain results. Many studies focused on the development and application of air quality models to study the growing problem of air pollution. Francisco (2011) used the revealed preference method to measure the benefits of improving air quality in Metro Manila when using cleaner public transport modes. Chen & Hashim (2016) studied the environmental and health co-benefits in the field of public transport. Recently, the importance of co-benefits has been emphasized in the process of implementing measures to mitigate GHG. This is identified as an important bridging tool between socio-economic development and environmental protection.

Fine particle matter is often used as the main indicator when assessing the level of air pollution and its impact is reflected in the number of respiratory illnesses recorded by hospitals. Quantifying the health co-benefit of GHG mitigation measures was mentioned in the study of Liou & Wu (2021). This study identified the mitigated GHG emissions and health co-benefit from reducing air pollution in switching from the usage of fossil fuel to electricity. Exposure to air pollution increases the risk of cardiovascular disease, stroke, lung cancer, and acute or chronic respiratory diseases. In particular, the health co-benefit associated with air pollution often considers the fine matter as a major indicator. In order to evaluate the health co-benefit, this study simulated the change in pollutant concentration when implementing a GHG mitigation measure, then calculated the change in a number of related cases to thereby estimating the economic value based on the value of VSL (Value of a Statistical Life)—a monetary indicator of health effects based on the loss of death. However, there are currently a limited number of studies that can integrate all three factors: public transport development, quantifying the GHG mitigation potential and co-benefits.

Rouil et al. (2009) used CHIMRE model to forecast and map the air quality for the European region. This study forecasted the PM_{10} and O_3 concentrations in real-time across Europe, thereby creating two sets of maps of PM_{10} and O_3 concentration distributions for the European region. Mohan et al. (2011) studied and evaluated the effectiveness AERMOD and ADMS-Urban model for total suspended particle concentration (TSP) in Delhi, India. These two models are applied to estimate the concentrations of surrounding particulate matter on seven locations in Delhi in 2000 and 2004. Results showed that the ADSM-Urban model provides better trend assessment results compared to the observed values, while the AERMOD model provides lower results compared to the observed values. The models are simulated with all emission point sources such as high point sources, vehicular traffic, and other emission sources in the city. The evaluation of the effectiveness of the models is checked based on the boundary class of the parameters in the models. The results of comparison and evaluation from the models will be a good reference source to support air quality management and the development of these models in the future.

Danish (2013) studied the application of the AERMOD model and spatial distribution visualization using ArcGIS. The model simulated the process of pollutant transmission in the air in Lima and the acquired results are highly accurate. Shukla et al. (2014) focused on evaluating the performance of the AERMOD model, the results showed that this model is suitable for all terrain.

In Viet Nam, a number of studies on air quality models have been conducted and initially put into application. Some specific studies are reviewed as follows: Ho et al. (2006) combined FVM, COPERT III, and TAPOM models to calculate the O_3 concentration in Ho Chi Minh city. The study showed that at the time of calculation (Jan. 8, 2003), the O_3 trail has the size of 90 km in width and 30 km in length (at 12:00) and the southwestern area of the city is the most polluted (180 ppb at 12:00). Truong & Duong (2007) used MM5 and CMAQ models to calculate the concentration of CO, NO_x, O_3, PM_{10}, SO_2 in Viet Nam and developed maps of concentration distribution of these gases for Viet Nam.

Ho et al. (2011) developed an integrated system to assess air pollution caused by road vehicles in Hue using a combination of AERMOD and GIS methods. As a result, a map of traffic pollution distribution was built for Hue. Nguyen (2015) applied the AERMOD model to simulate and evaluate air pollution from production activities for Formosa Ha Tinh Iron and steel factory. This study focused on the following issues: assessing the current status of air quality in the project area, collecting data on the expected emission source of the factory, meteorological and topographic data. In addition, information is also collected on sensitive areas around the project area. Based on results from the AERMOD model, forecasting and mapping of pollution distribution of NO_2, SO_2, TSP according to scenarios have been made to assess the air pollution in the worst scenario. Nguyen (2016) applied the AERMOD model and GIS technique to simulate air quality in Thi Vai River. The air quality assessment in Thi Vai River is based on calculating the concentration of air pollutants SO_2, NO_X, CO, TSP, THC/VOC to build a simulated air quality map for the area. AERMOD model has been applied to simulate the atmosphere for Bim Son cement factory, Thanh Hoa. The AERMOD model allowed paying attention to the surrounding terrain elements of Bim Son cement factory that other models have not considered. The results have been verified with measured data, allowing confirming the reliability of the calculated results. However, the model has only been applied for point emission sources; application to mobile sources such as pollution sources caused by vehicles has not been implemented.

With Viet Nam's current conditions, using mathematical models with a large enough volume of meteorological data will results in faster, more accurate, and efficient calculations compared to using a small number of monitored, measured data. On the other hand, it also offers high economic efficiency when the equipment for measuring air pollution is still limited. Some two-dimensional air pollution distribution models (MESOPUFF), Sutton (Bui, 2008), TAPM-AERMOD (Vu et al., 2018), ISC 3, etc. based on the analysis of air pollution studies and applied models.

In Viet Nam, there have been some initial studies to evaluate individual co-benefits in the transport sector. However, there is a limited number of studies that comprehensively evaluate the socio-economic-environmental co-benefits of GHG mitigation measures in the public transport sector. Commonly calculated co-benefits to assess the impacts of GHG mitigation measures in the transport sector include energy-saving, travel time reduction, carbon credit, and health-related air pollution. This study selected the AERMOD model to simulate about 70 main roads of Ha Noi with meteorological data taken directly from the GFS global model to forecast a number of emission scenarios in the public transport sector. Calculated results of pollutant emission from traffic sources used to calculate the health co-benefit of modal shifting from motorbike to public transport for the people of Ha Noi. This is the highlight of the study as quantification of co-benefit is considered relatively new and has never been attempted in Ha Noi. The results of this study can further explore the impacts of mitigation measures being implemented to achieve the goal of the Paris Agreement.

2. Materials and Methods

2.1. Description of Study Site

Ha Noi is in the Northern Delta, located from 20˚53' to 21˚23' north latitude and 105˚44' to 106˚02' east longitude, adjacent to the provinces: Thai Nguyen, Vinh Phuc in north; to the south, it borders Ha Nam and Hoa Binh; the east borders the provinces of Bac Giang, Bac Ninh, and Hung Yen; to the west, it borders Hoa Binh and Phu Tho provinces. Ha Noi is located on the right bank of the Da River and on both sides of the Red River, the location and location are favorable for an important political, economic, cultural, scientific, and transportation center of Vietnam.

The average annual humidity in Ha Noi is 83%. The period from late summer to early winter (XI - XII) is a relatively dry period, the average monthly humidity in Ha Noi is only 80%. In the period from March to April, due to wet and drizzly weather, the average monthly humidity reaches the highest level of the year at 87% in Ha Noi, the humidity range in the day is only 20% - 30%. The months between the rainy seasons are relatively high, averaging 83% - 84% in Ha Noi.

According to the statistics Prime Minister (2016), the city's main mode of personal passenger transport is motorbikes, accounting for a very high 85% of vehicle mode share. Currently, public transport mainly depends on buses, however, the mode share of transport by buses is only 15%. The deployment of BRT bus routes and sky trains is still facing many difficulties and delays. The Kim Ma—Le Van Luong—Yen Nghia BRT route has been put into operation since 2018 but the transport capacity of the whole route is only 50% of the expected capacity. The separate lane for this type of vehicle also has many inadequacies in implementation, making the traffic speed relatively low, not really effective. Regarding urban railways, Line 2A (Cat Linh Line): Cat Linh—Ha Dong, and Line 3 (Temple of Van Mieu), Nhon—Ha Noi Station section are the first two railway lines to be built. The construction of railway lines is currently behind schedule and is heavily funded due to the lengthy construction process. Line 2A has missed the completion schedule 8 times and has not officially come into commercial operation so far. Line 3, section Nhon—Ha Noi Railway Station, has also had to adjust its schedule twice and is expected to be fully operational by the end of 2022.

According to the Transport Planning of Ha Noi Capital to 2030, with a vision to 2050, types of passenger transport modes of Ha Noi Capital in the period after 2020 will include bicycles, cars machines, cars, regular buses, BRT buses, and sky trains. Each type of vehicle will have different advantages and disadvantages, depending on the circumstances, conditions, and goals, the proportions of these vehicles will be adjusted and used appropriately. In particular, the Planning of Ha Noi has paid a great deal of attention to public transport, in which, prioritizing investment and development to gradually increase the rate of public transport in stages (**Table 1**).

Based on the above objectives and studies forecasting the transport demand, this master planning has determined the implementation roadmap and corresponding cost estimates for various types of public transport in the period of 2020-2030, shown in **Table 2**.

Based on the roadmap, in the period of 2020-2030, regular buses, BRT, and sky train will be the main focus of public transport in Ha Noi Capital, toward becoming the main form of passenger transport, replacing personal vehicles (**Figure 1**).

Table 1. Orientation of the development of public transport in Ha Noi (Prime Minister, 2016).

	Period	Rail	Bus	Total
Urban area	2020	10% - 15%	20%	30% - 35%
	2030	25% - 30%	25%	50% - 55%
	After 2030	35% - 40%	30%	65% - 70%
Rural area	2020	10%	15%	15%
	2030	15%	25%	40%
	After 2030	20%	30%	50%

Table 2. Roadmap for investment in public transport in Ha Noi period 2020-2030 (Prime Minister, 2016).

No.	Vehicles	Investment in period 2020-2030	Total investment (Billion VND)
1	Urban rail	8 lines	420.407
2	Monorail	3 lines	46.332
3	BRT	8 lines, 771 vehicles	51.996

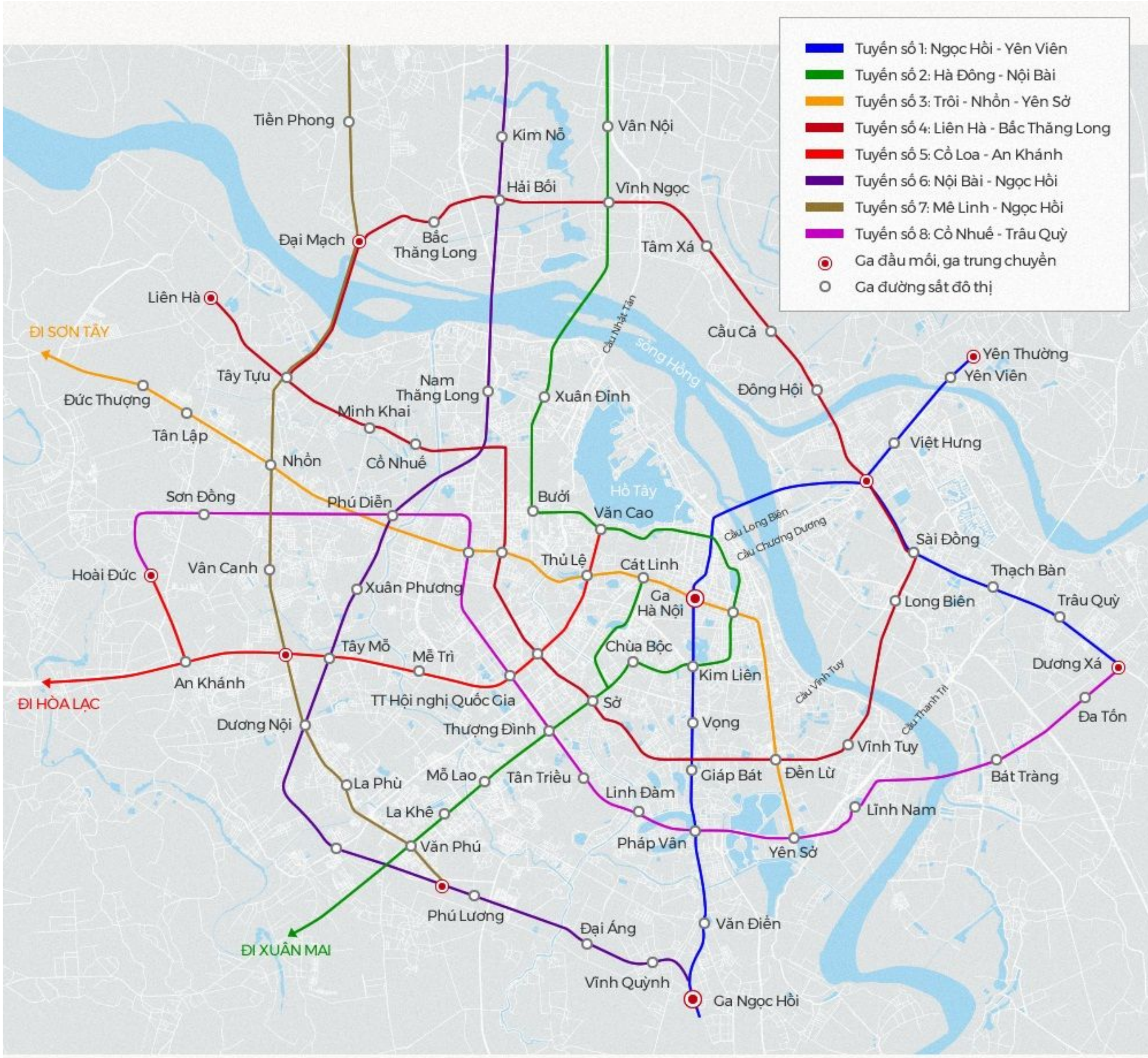


Figure 1. Planning of urban railway transport system in Ha Noi (Prime Minister, 2016).

2.2. Health Co-Benefit Related to Air Pollution

The main causes of cardiovascular and respiratory diseases from passenger transport activities include Lead, Ozone, fine dust, Nitrogen Dioxide, Carbon Monoxide, and Sulfur Dioxide (Ho, 2010). In particular, $PM_{2.5}$ fine dust was identified as the main source of various diseases related to air pollution. Fine dust refers to extremely small particles, both liquids and solids, which exist in the air. These particles are very small, they can penetrate the lungs, blood vessels and cause significant damage to health. Fine dust can come from many different sources, but the burning of fossil fuels is one of the main causes of air pollution. Therefore, the health co-benefits from air pollution will be calculated through the impact of the change in $PM_{2.5}$ fine dust concentration due to urban public transport activities on the number of deaths due to air pollution exposure to fine dust $PM_{2.5}$.

When the concentration of pollutants in the air decreases, the number of people suffering from respiratory and cardiovascular diseases will decrease and thereby obtain health co-benefits. Health co-benefits would include changes in morbidity and mortality rates. Liou & Wu (2021) has shown that mortality accounts for 98% of the health benefits from reducing air pollution, with morbidity accounting for only the remaining 2%. Thus, mortality rates from respiratory and cardiovascular diseases can be used to represent health benefits from air pollution. To assess the health co-benefits from air pollution, the impact of GHG emission mitigation measures on the volume and concentration of $PM_{2.5}$ fine dust causing air pollution within Ha Noi needs to be determined.

Total amount of air pollution emitted from vehicles:

$$E_i = \sum EF_{ij} \times VKT_j \times 10^{-3} \quad (1)$$

E_i is the total emission of pollutant gas (tons); $EF_{i,j}$ is emission factor i for vehicle type j (g/km); VKT_j is the annual traveled distance of vehicle type j (km); 10^{-3} is the conversion factor from kg to tons.

The determination of changes in concentrations of air pollutants will use the AERMOD model (**Figure 2**). This is a model to support the description of the pollutant transmission process within the city, taking into account meteorological and topographic factors. AERMOD includes two tools to support data mining and processing: AERMET meteorological tool and AERMAP terrain tool:

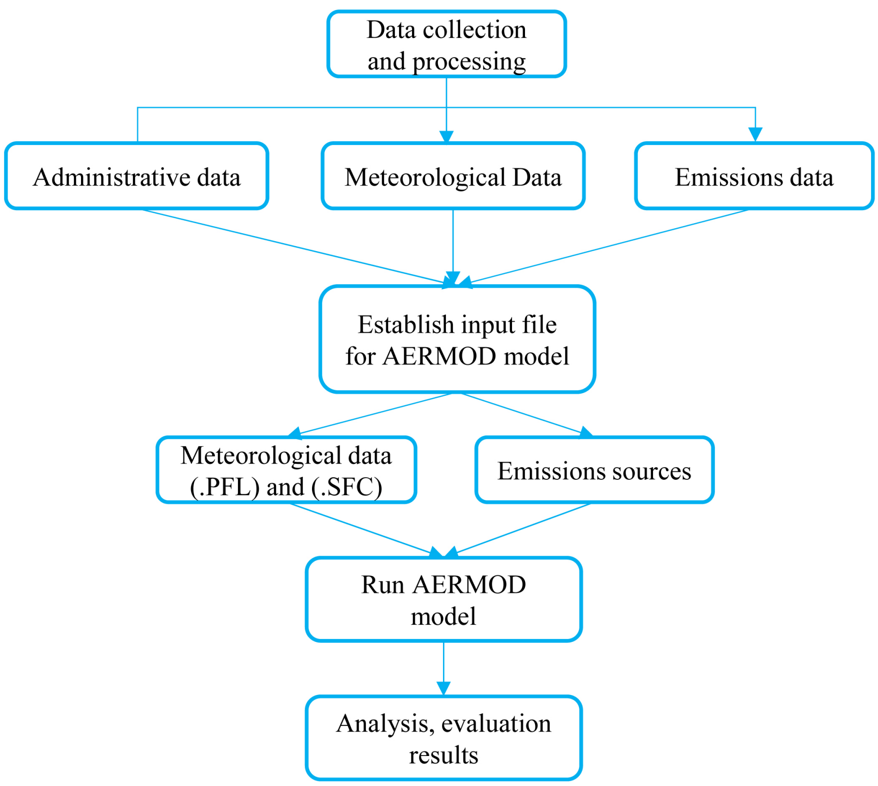


Figure 2. AERMOD model application diagram.

- Meteorological tools (AERMET): use meteorological measurements, to calculate certain boundary layer parameters, process surface meteorological data on different layers, deal with wind direction, speed wind, temperature, and altitude.
- The Terrain Tool (AERMAP) has the main purpose of showing the physical relationship between the topographic features and the activity of air pollutants. This tool generates height and data for each location and provides information that allows dispersion models to simulate air impacts.

When describing the process of pollutant diffusion in the air using mathematical models, the level of air pollution is usually characterized by the concentration of the pollutant concentration in space and changing over time. In the general case, the average value of the pollutant concentration in the air distributed over time and space is described from the full chemical transfer and chemical transformation equations as follows (Dinh, 2007):

$$\begin{aligned}&\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+\upsilon\frac{\partial C}{\partial y}+\omega\frac{\partial C}{\partial z}\\&=\frac{\partial}{\partial x}\left(k_x\frac{\partial C}{\partial x}\right)\frac{\partial}{\partial y}\left(k_y\frac{\partial C}{\partial x}\right)\frac{\partial}{\partial z}\left(k_z\frac{\partial C}{\partial x}\right)+\alpha C-\beta C+\omega_c\frac{\partial C}{\partial z}\end{aligned} \tag{2}$$

where C is the concentration of pollutants in the air; x, y, z are coordinate components along the axes O_x, O_y, O_z; t is the time; k_x, k_y, k_z are the components of the turbulent diffusion coefficient along the axes O_x, O_y, O_z; u, v, w are the components of wind speed along the axis O_x, O_y, O_z; is the deposition rate of pollutants; α is the factor that takes into account the association of the pollutant with other elements of the atmosphere; β is a factor that takes into account the conversion of pollutants into other substances due to chemical reaction processes occurring on the propagation path.

The Basic Gaussian Plume Equation for pollutant dispersion (Venkatram, 2008):

$$\begin{aligned}&C_S\left\{x_r,y_r,z\right\}\\&=\frac{Q}{\sqrt{2\pi}\bar{u}\sigma_{zs}}\cdot F_y\cdot\sum_{m=-\infty}^{\infty}\left[\exp\left(-\frac{\left(z-h_{cs}-2mz_{ieff}\right)^2}{2\sigma_{zN}^2}\right)+\exp\left(-\frac{\left(z+h_{cs}+2mz_{ieff}\right)^2}{2\sigma_{zN}^2}\right)\right]\end{aligned} \tag{3}$$

where $C_S\{x_r, y_r, z\}$ is the total concentration of pollutants; Q is the emission rate of the pollutant source (g/s); u is the wind speed (m/s); σ_{zs} is the concentration dispersion distance for the fixed source (m); z_{ieff} is the terrain height (m); h_{es} is the height of the source (m); m is the volume of fuel consumed (tons/hour).

After assessing the change in concentrations of pollutants under the scenarios, the widely used health impact function takes the form below to evaluate the health co-benefits (Liou & Wu, 2021).

$$\Delta y=\left(1-e-\beta\Delta x\right)\times y_0 \tag{4}$$

where Δy is the change in disease incidence (%); Δx is the change in pollutant concentration; β is the correlation coefficient between concentration and disease incidence; y_0 is the mortality rate caused by air pollution.

The predicted number of deaths caused by air pollution can be determined based on the change in morbidity due to changes in air pollutant concentrations and the population affected. The change in air pollution-related deaths will be estimated and converted to a monetary value based on the value of a statistical life (VSL). VSL is a widely used monetary index in health benefits studies (Manisalidis et al., 2020); this index represents people's willingness to pay to reduce a certain proportion of mortality risk. Currently, in Vietnam, studies and surveys on VSL values have not been carried out and are still using the results of international studies. The benefit transfer approach will be applied with the VSL value of a country that has done the same research and converted to the VSL value of Vietnam according to the Equation (5):

$$\mathrm{VSL}_{\text{Viet Nam}} = \mathrm{VSL}_{\text{Reference}} \times \left(\mathrm{GDP}_{\text{Viet Nam}} / \mathrm{GDP}_{\text{Reference}}\right) \tag{5}$$

Once the change in air pollution-related deaths and the corresponding Vietnam VSL values are determined, the health co-benefits can be evaluated using the Equation (6):

$$\mathrm{L3} = \Delta D \times \mathrm{VSL} = \left(\Delta y \times P\right) \times \mathrm{VSL} \tag{6}$$

where ΔD is the change in number of death (number of cases); VSL is the value of a statical life (VND); P is the population (people).

2.3. Data Collection

- The average daily travel coefficient of people and distance traveled is assumed to be remain a contract, based on survey data from the Transport Planning of Ha Noi Capital to 2030, with a vision to 2050 (Prime Minister, 2016).
- The fuel consumption of passenger transport vehicles is assumed to remain constant over the calculated period. A vehicle or fuel technology transition that affects fuel consumption and fuel emission factors often requires a long period of time to be fully adopted. Therefore, for the period of 2020-2030, changes related to these factors will be assumed to be negligible.
- The mode share for bicycles and cars will remain constant in the period of 2020-2030.
- The traffic volume is based on vehicle count data at some routes in Ha Noi. Vehicle counting is conducted from 6 h to 20 h for 12 types of vehicles (**Table 3**).
- The meteorological data is taken from the Lang station of the Hydrometeorological Station of the Northern Delta. The Lang station is a level 3 meteorological station that measures the following factors: Temperature, humidity, pressure, cloud cover, wind speed, wind direction, rain volume.

In addition, some input data has been collected and aggregated for use in calculations. The input data includes vehicle specifications and types of fuel used in urban public transport (**Table 4**).

Table 3. Specifications of public transport vehicles (TEDI, 2016).

	Motorbike	Car	Buses	BRT	Electric train
Average distance traveled (km/trip)	6.49	14.74	19.68	19.68	5.3
Surveyed average occupancy factor (passenger/vehicle)	1.24	1.72	30	40.1	NA
Maximum occupancy factor (passenger/vehicle)	2	4	60	90	900
Average fuel consumption (l/100km or kWh/110km*)	2.5	10.00	29.26	37	2280.00*
Average speed (km/h)	40	30	30	30	35

Table 4. Specifications of fuels used in transportation.

	Gasoline	Diesel	Electric
Weight (tons/l)	0.0007425[a]	0.0008320[a]	19.68[a]
Net calorific value (TJ/tons or TJ/kWh)	0.0440[a]	0.0425[a]	0.0000036[a]
CO_2 emission factor (kg CO_2/TJ or kg CO_{2e}/kWh)	68.607.0[a]	73.326.0[a]	0.913[b]
CH_4 emission factor (kg CH_4/TJ)	20.0[a]	5.0[a]	0[a]
N_2O emission factor (kg N_2O/TJ)	0.6[a]	0.6[a]	0[a]
Selling price (VNĐ/l or VNĐ/kWh*)	13.220[c]	11.040[c]	2.528*[d]

[a]IPCC (2006), [b]MONRE (2020), [c]Viet Nam Petrolimex, [d]EVN.

2.4. Developing Scenarios for Modal Shifting from Motorbike to Public Transport Vehicles

Given that the technology and fuel types remain unchanged in the period of 2020-2030, the occupancy factor of public transport vehicles needs to be improved to increase the GHG mitigation potential when shifting from motorbikes to public transport. The following occupancy factors were selected to evaluate the health co-benefits of air pollution (Table 5).

2.4.1. Base Scenario

With this scenario, the population of Ha Noi city will continue to grow, the vehicle occupancy factor will be assumed unchanged and no additional GHG mitigation measure will be implemented in the period 2020-2030 (Table 6).

2.4.2. Scenario 1 (S1): Model Shifting from Motorbike to Traditional Buses

According to the Transport Planning of Ha Noi Capital to 2030, with a vision to 2050, in order to solve the problem of traffic congestion and air pollution from transportation activities for Ha Noi, the plan to regulate and limit the use of

Table 5. Occupancy factor of public transport vehicles.

	O1	O2	O3
Traditional buses	38 (63%)	43 (70%)	48 (80%)
BRT	59 (65%)	65 (70%)	72 (80%)
Electric train	339 (38%)	396 (44%)	450 (50%)

Table 6. Ha Noi's transport mode share in base scenario (Unit: %).

Year	Bicyle	Motorbike	Car	Bus	BRT	Train
2020	10.00	65.00	10.00	15.00	0	0
2025	10.00	65.00	10.00	15.00	0	0
2030	10.00	65.00	10.00	15.00	0	0

motorbikes will be implemented. Specifically, according to the roadmap, it is expected that the mode share of motorbike will gradually decrease and reach 17% in 2030.

Under Scenario 1, 48% of mode share of motorbikes will be shifted to regular buses with a transition rate of 4.8%/year and 3 levels of occupancy factors from low to high will be applied. The mode share of other vehicle types will remain unchanged as in the base scenario (Table 7).

2.4.3. Scenario 2 (S2): Model Shifting from Motorbike to BRT

Under Scenario 2, 48% of mode share of motorbike will be shifted to BRT with a transition rate of 4.8%/year and 3 levels of occupancy factors from low to high will be applied. The mode share of other vehicle types will remain unchanged like in the base scenario (Table 8).

2.4.4. Scenario 3 (S3): Modal Shifting from Motorbike to Electric Train

Under Scenario 3, 48% of mode share of motorbike will be shifted to sky train with a transition rate of 4.8%/year and 3 levels of occupancy factors from low to high will be applied. The mode share of other vehicle types will remain unchanged like in the base scenario (Table 9).

3. Results and Discussion

3.1. Health Co-Benefits from Air Pollution in the Scenario of Shifting from Motorbikes to Regular Buses (S1)

Air pollution co-benefits will determine the number of deaths caused by $PM_{2.5}$ fine dust from public transport. For Scenario S1, the total amount of $PM_{2.5}$ fine dust emitted in the period from 2020 to 2030 will reach O1: 19,017.63; O2: 17,552.82 and O3: 16,393.19 tons, both increased compared to the base scenario

Table 7. Ha Noi's transport mode share in Scenario S1 (Unit: %).

Year	Bicyle	Motorbike	Car	Regular Buses	BRT	Skye train
2020	10.00	65.00	10.00	15.00	0	0
2025	10.00	41.00	10.00	39.00	0	0
2030	10.00	17.00	10.00	63.00	0	0

Table 8. Ha Noi's transport mode share in Scenario S2 (Unit: %).

Year	Bicyle	Motorbike	Car	Regular Buses	BRT	Skye train
2020	10.00	65.00	10.00	15.00	0	0
2025	10.00	41.00	10.00	15.00	24.00	0
2030	10.00	17.00	10.00	15.00	48.00	0

Table 9. Ha Noi's transport mode share in Scenario S3 (Unit: %).

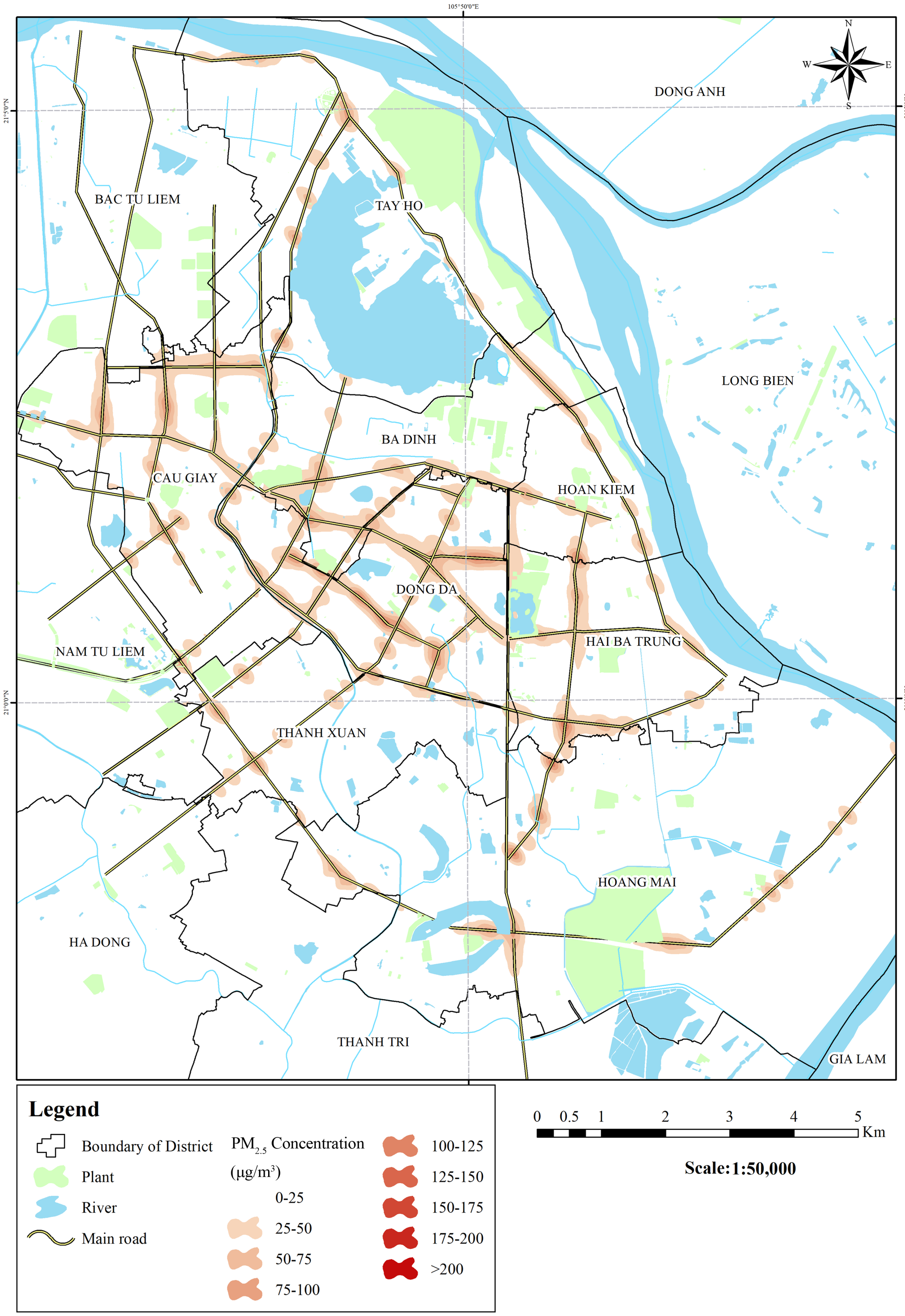
Year	Bicyle	Motorbike	Car	Regular Buses	BRT	Skye train
2020	10.00	65.00	10.00	15.00	0	0
2025	10.00	41.00	10.00	15.00	0	24.00
2030	10.00	17.00	10.00	15.00	0	48.00

of 14,671.21 tons. An increase in the total amount of dust will increase the dust concentration in the city and increase the risk of death related to respiratory diseases. The change of $PM_{2.5}$ dust concentration between the S1 scenario and the baseline scenario is simulated using the AERMOD model. Simulation results on distribution and concentration of fine dust $PM_{2.5}$ in 2030 between the two scenarios shown in Figure 3.

Simulation results of the AERMOD model show that, on average, for each ton of $PM_{2.5}$ dust reduced, the concentration of this substance decreases by about 0.00006 ug/m^3 within Hanoi city. Corresponding to the increase in total $PM_{2.5}$ dust, $PM_{2.5}$ dust concentration also increases in the period from 2020 to 2030.

After assessing the change in the concentration of $PM_{2.5}$ fine dust, Equation (3) was used to quantify the co-benefit value. The predicted number of deaths caused by air pollution can be determined based on the change in morbidity due to changes in $PM_{2.5}$ fine dust concentration and the affected population. The change in air pollution related deaths will be estimated and converted to monetary value based on the VSL value. Within the scope of the research, with the limitations of data, time and research scale, the thesis cannot assess the VSL value of Hanoi people. Therefore, the thesis will use the benefit conversion approach to inherit the results from a number of relevant studies conducted in Taiwan on the assessment of health co-benefits related to $PM_{2.5}$ fine dust concentration. Accordingly, the value of Taiwan's VSL in 2017 is 3.42 million USD, this value will be converted based on the difference in GDP between the two countries:

$$\mathrm{VSL}_{\text{Viet Nam}} = \mathrm{VSL}_{\text{Taiwan}} \times \left(\mathrm{GDP}_{\text{Viet Nam}} / \mathrm{GDP}_{\text{Taiwan}}\right) = 1.6 \text{ million USD}$$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N
S
W
E
DONG ANH
BAC TU LIEM
TAY HO
LONG BIEN
BA DINH
CAU GIAY
HOAN KIEM
DONG DA
HAI BA TRUNG
NAM TU LIEM
THANH XUAN
HOANG MAI
HA DONG
THANH TRI
GIA LAM
Legend
Boundary of District
Plant
River
Main road
PM2.5 Concentration
(μg/m³)
0-25
25-50
50-75
75-100
100-125
125-150
150-175
175-200
>200
0 0.5 1 2 3 4 5
Km
Scale:1:50,000

(a)

(b)

Figure 3. Distribution map of $PM_{2.5}$ concentration of Scenario S1 in 2030: (a) Base scenario; (b) Scenario 1.

The VSL value of 2017 will then be adjusted for inflation at 6%/year to obtain the value of 2020:

$$\text{VSL}_{\text{Viet Nam 2020}} = \text{VSL}_{\text{Viet Nam 2017}} \times (1+r)^3 = 1.91 \text{ million USD}$$

Using Equation (3) with parameters: VSL value is 1.91 million USD/person; Forecast of Hanoi's population from 2020 to 2030; The mortality rate due to air pollution is 0.01015%; β coefficient is 0.0013103 to quantify the health co-benefit on the change in morbidity due to changes in $PM_{2.5}$ fine dust concentrations and the affected population. The resulting health co-benefit under Scenario S1 is presented in **Figure 4**.

The 2020 present value of the air pollution co-benefits in the S1 scenario is −6044.84; −3803.31; −2028.95 billion VND corresponding to 3 levels of increasing occupancy factor. The co-benefit tends to decrease as the conversion rate from motorbikes to buses increases as the $PM_{2.5}$ emission factor of the bus is usually 0.09 g/km, which is relatively high compared to that of the motorbike at 0.002 g/km. Shifting from motorbikes to regular buses with occupancy factors applied would have the potential to reduce GHG emissions, however, could increase $PM_{2.5}$ fine dust and associated increased risk of deaths related to air pollution.

3.2. Health Co-Benefits from Air Pollution in the Scenario of Shifting from Motorbikes to BRT (S2)

Scenario S1, the total amount of $PM_{2.5}$ fine dust emitted in the period from 2020 to 2030 is O1: 17,299.38 tons; O2: 16,077.05 tons; O3: 15,110.60 tons are all increased compared to the base scenario of 14,671.21 tons. An increase in the total amount of dust will increase the dust concentration in the city and increase the risk of death related to respiratory diseases. The change of $PM_{2.5}$ dust concentration between the S2 scenario and the baseline scenario is simulated using the AERMOD model shown in **Figure 5**.

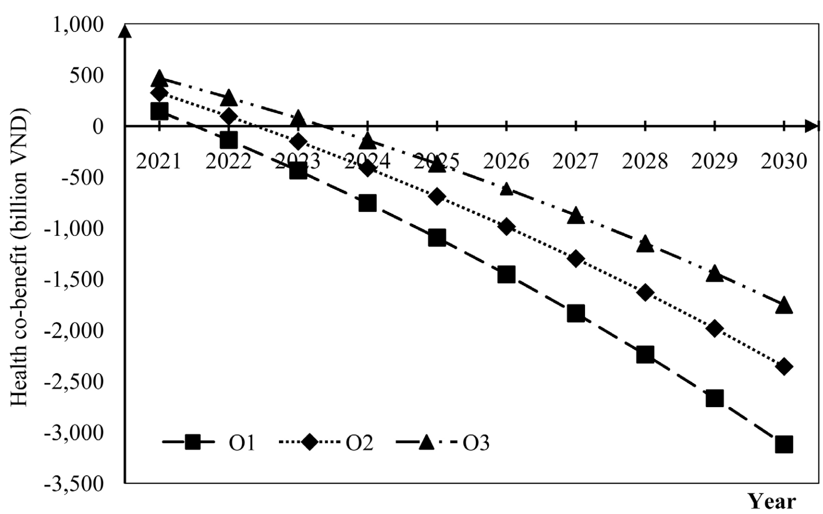

Figure 4. Health co-benefits of Scenario S1.

Figure 5. Distribution map of $PM_{2.5}$ concentration of Scenario S2 in 2030.

The simulation results of the AERMOD model show that, if the conversion of 48% of motorbike use to BRT is completed, the concentration of $PM_{2.5}$ fine dust will increase significantly at intersections in Hanoi. The average concentration increased to 50 - 75 μg/m^3 at most of the roads. Especially, at traffic junctions, the average concentration of $PM_{2.5}$ fine dust reaches 75 - 100 μg/m^3 and some points reach 100 - 125 μg/m^3.

Using Equation (3) with parameters: VSL value is 1.91 million USD/person; Forecast of Hanoi's population from 2020-2030; The mortality rate due to air pollution is 0.01015%; The β coefficient was 0.003103 to quantify the health co-benefit on the change in morbidity due to changes in $PM_{2.5}$ fine dust concentrations and the affected population. The detailed results are as shown in Figure 6.

The 2020 present value of the health co-benefits in the S2 scenario is −3556.38; −1646.26; −154.46 billion VND. The value of co-benefits tends to increase as the occupancy factor increases.

3.3. Health Co-Benefits from Air Pollution in the Scenario of Shifting from Motorbikes to Electric Trains (S3)

Scenario S3, the total amount of $PM_{2.5}$ fine dust emitted in the period from 2020 to 2030 is O1: 10,917.09 tons; O2: 10,394.21 tons; O3: 9980.26 tons, down from 14,671.21 tons in the base scenario. A reduction in the total amount of dust will contribute to a reduction in dust concentrations in the city and a reduction in the risk of death related to respiratory diseases. The change of $PM_{2.5}$ dust concentration between the S3 scenario and the baseline scenario is simulated using the AERMOD model shown in Figure 7.

The simulation results of the AERMOD model show that, if the conversion of 48% of motorbike use to electric trains is completed, the concentration of $PM_{2.5}$ fine dust will be significantly reduced at intersections in Hanoi. The average concentration is 25 - 50 μg/m^3 at most of the roads.

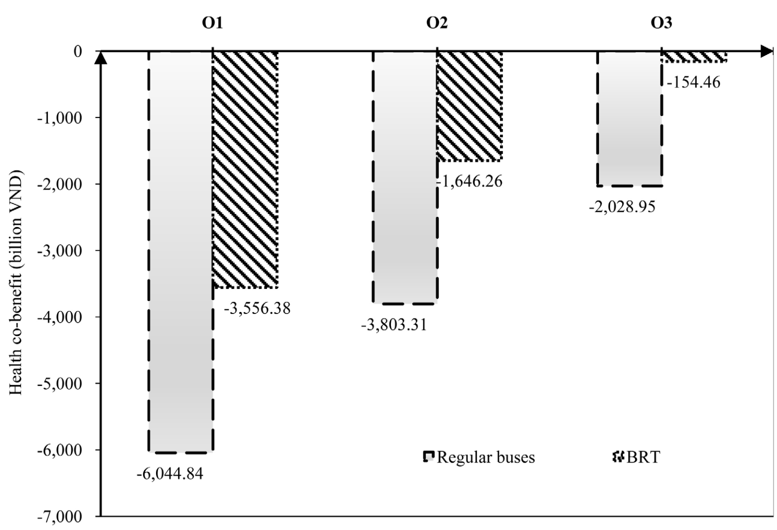

Figure 6. Health co-benefits of Scenario S2.

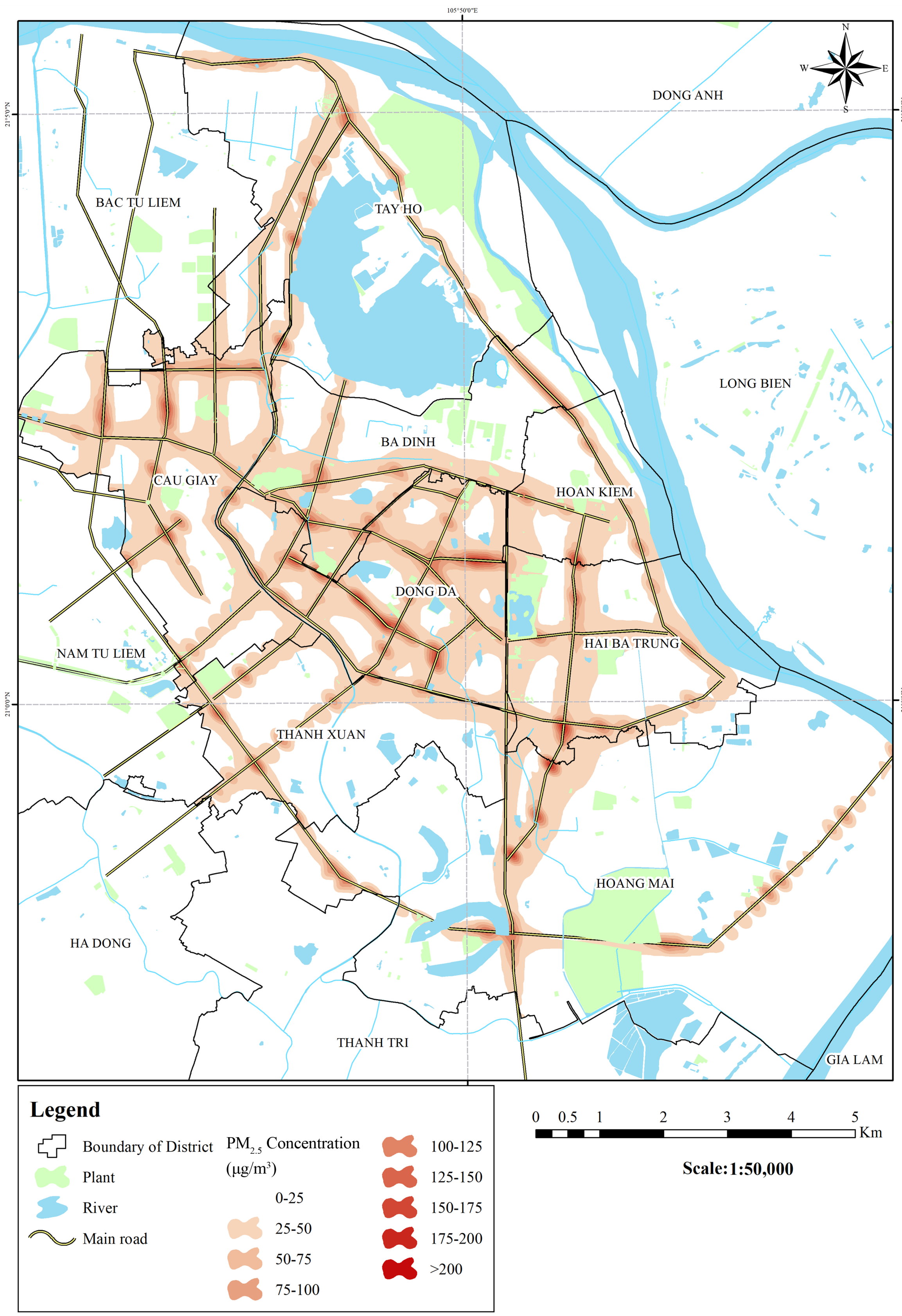

Figure 7. Distribution map of $PM_{2.5}$ concentration of Scenario S3 in 2030.

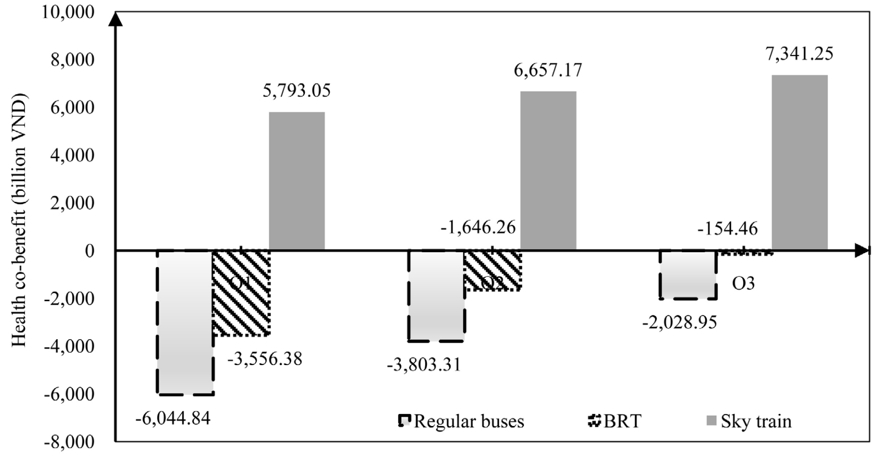

Figure 8. Health co-benefits of Scenario S3.

Using Equation (3) with parameters: VSL value is 1.91 million USD/person; Forecast of Hanoi's population from 2020 to 2030; The mortality rate due to air pollution is 0.01015%; The β coefficient was 0.003103 to quantify the health co-benefit on the change in morbidity due to changes in $PM_{2.5}$ fine dust concentrations and the affected population. The detailed results are as shown in Figure 8.

The 2020 present value of the health co-benefits in the S3 scenario is 5793.05; 6657.17; 7341.25 billion VND. The value of co-benefits tends to increase as the train's occupancy factor level increases. This is the only scenario where the health co-benefits are positive and the only vehicle that uses electric fuel, so there are no dust emissions from fuel combustion as for conventional buses and BRT express bus.

4. Conclusion

Estimating the health co-benefits of GHG emission reduction measures in the public transport sector in Hanoi allows conclude are as follows:

1) The health co-benefits of the scenarios in the public transport sector in Hanoi in the period 2020-2030 are very significant numbers. Shifting from motorbikes to regular buses and BRT still increases the total amount and concentration of $PM_{2.5}$ fine dust in the air, which in turn can increase the number of deaths due to air pollution. However, when using the sky train as an alternative, the health co-benefits are positive and can reach 7341 billion VND when the occupancy factor is increased. This showed the advantages that electric vehicles have over combustion vehicles, as there is no fuel combustion in operation. This presented a pathway to further evaluate the socio-economic-environmental impacts of electric vehicles including both personal and public vehicles to promote the use of renewable energy in the transport sector.

2) The evaluation of co-benefits depends heavily on the completeness and accuracy of the database. In the future, it is necessary to supplement surveys, mea-

surements and improve the database in the public transport sector in general and the greenhouse gas inventory, in general, to reduce uncertainty in the results of calculation and assessment when evaluating the impacts of GHG mitigation measures.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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