Photochemical modeling of PM$_{2.5}$ and design measures for PM$_{2.5}$ reduction: A case of Ho Chi Minh City, Vietnam

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Abstract. Vietnam’s urban areas have faced with serious environmental pollution issues, including: water pollution, municipal waste and air pollution. Air in Ho Chi Minh city is polluted by PM$_{2.5}$ (particle matter with the diameter is less than 2.5 µm, so-called PM$_{2.5}$), O$_3$, CO, NO$_2$ and TSP which greatly affects public health. In 2017, Ho Chi Minh City (HCMC) had 8,640,000 inhabitants with a total of 7,339,552 motorcycles and 637,323 automobiles. There are about 2,500 factories, 2,061,957 household and 5,096 restaurants in the city. The aim of this study is to (i) conduct a detailed air pollution emission inventory for PM$_{2.5}$; (ii) stimulate PM$_{2.5}$’s dispersion in HCMC and (iii) propose mitigation measures for PM$_{2.5}$ in the city. Simulations of air pollution were conducted in HCMC by using TAPM-CTM system model. The model performance was evaluated using observed meteorological data at Tan Son Hoa station and air quality data at the Ho Chi Minh City University of Science. The result states that the sum of air pollutants from main sources of disposal in HCMC is 3,978.32 ton of PM$_{2.5}$ in 2017. Average maximum 1 hours, 24 hours and annual of PM$_{2.5}$ concentration in 2017 does not exceed QCVN 05:2013/BTNMT, but it is 1.3 to 2.3 times higher than the WHO’s guideline. Therefore, the PM$_{2.5}$ in HCMC impacts on public health of HCMC. To control and manage the air’s quality and minimize the generation of PM$_{2.5}$ in HCMC there are possible solutions such as the control of air pollutants from the main source, the creation of encouraging policy, the regulation of air pollutants in HCMC and the raising people’s awareness of environmental protection.
1. Introduction

Ho Chi Minh City (HCMC) is located at 10045’N and 106045’E in the Southeastern region of Vietnam. There are 19 central districts and 5 suburban districts. HCMC’s economic growth rate has been skyrocketing in recent years. The population of HCMC is 8.6 million people, the number of private vehicles is about 9 million units. Currently, there are 19 manufacturing and industrial zones, 30 industrial clusters on an area of 1,900 ha, and numerous factories and enterprises located separately in HCMC [1, 2]. The huge volume of household cooking fuels, private traffic in the area, and industrial units in and around the city release significant amounts of pollutants into the atmosphere.

The results show that the highest concentrations of CO, NOx, and O3 in 2017 exceeded the National technical regulation in ambient air quality (QCVN 05:2013/BTNMT) 1.5, 1.5, and 1.1 times, respectively [2]. These harmful pollutant concentrations have negative impacts on human health of people, environmental and social issues in HCMC [3,4]. It is an urgent need to design abatement for reducing air pollution in the city which requires information on air pollution emission inventory and the formation of air pollution plume over the city. Particularly, in HCMC, PM2.5 data is unavailable, to improve the air quality, the spread of PM2.5 in the atmosphere should be well calculated, simulated, and evaluated to seek a method of management and control. Therefore, the research on “Develop PM2.5 emission inventory, photochemical modeling of PM2.5 and design measures for PM2.5 reduction: A case of Ho Chi Minh City, Vietnam” was carried out. The aim of this study is: (i) to conduct a detailed air pollution emission inventory for PM2.5; (ii) stimulate PM2.5 spreading in HCMC and (iii) propose mitigation measures for Ho Chi Minh City.

There are 3 major emission sources in HCMC, including industrial, household cooking and traffic activities, distributed as point, area, and line source. Industrial and Household cooking source used emission inventory method from the European Environment Agency (EMEP/EEA air pollutant emission inventory guidebook – 2016). HCMC is a developing city, it lacks information on traffic for doing detailed/bottom-up air pollution emission inventory and a top-down approach has relatively high uncertainty. Therefore, a combination of bottom-up and top-down approaches [5,6] is adopted for doing air emission inventory using the EMISENS (EMIssion SENSitivity) model [7,8]. After the pollutants are ejected into the atmosphere, they will be transformed by a series of complex processes (atmospheric dynamics, chemistry, solar radiation, etc.). Numerical air quality models are able to account for all these processes, they constitute the only reasonable approach to understand and control air pollution [9]. In this research, TAPM-CTM system model was used for studying the formation of the pollution plume.

2. Materials and Methods

Three main stages: air pollution emission inventory; meteorology simulation, air quality modeling, and proposal mitigation measures air pollution are described in generalized study processes in Figure 1. Emission inventory aims to provide comprehensive source data and distribute emissions across space; TAPM is a meteorological model, that produce input data to CTM – air quality model, in order to generate an air pollution map. Finally, based on the results, the research is offered abatement strategies to reduce air pollution in HCMC.

2.1 Air emission inventory

Sources of PM2.5 emissions in HCMC are divided into three major groups: point sources, area sources, and line (or mobile) sources as described in Table 1. Point and area source emissions are calculated using emission factors (EFs) and activities data as in Eq. (1). The mobile source is calculated using EMISENS model.

\[ E = A \times EF \times [1-(ER/100)] \]  \hspace{1cm} (1)

Where E is emissions (normally in tons/year), A is activities rate (amount of fuel use, capacity or number of products) and EF is emission factors (related to A), ER is emission reduction efficiency (only if abatement devices are used). Note that most of EFs using in this study were adopted from EMEP/EEA.
air pollutant emission inventory guidebook – 2009. the others were from local study and would be mentioned in detailed. For point sources: we collected more than 1000 factories inside and outside industrial zones with information on fuel type, amount of fuel used, technology, air pollution treatment, etc. Exhausted emissions from burning fuel and operation processes were taken into account. Air pollution loads were calculated based on related EFs.

For area sources, This study is calculating the emission of more than 2,000,000 households and 5,069 restaurants for 24 districts in the city. Other activities such as pagodas, construction works, and building material are collected [2].

Data was collected through surveys. The survey objective was to find out how much energy an activity consumed at the mean levels included in the equation (1) for point sources and equation (3) for area sources, shown hereafter. For point sources: to estimate the amount of emissions, the quantity of each type of energy consumed, the capacity and the production of the company was the key information to obtain in the survey”. For traffic sources: the input data for the model were gathered from the questionnaires that include the information about the number of trips per day, the engine technology, type of fuel use, number of trips per day, and average mileage. For area sources: “Emissions from area sources were estimated based on the average amount of fuel consumption (including LPG, coal, charcoal, wood, etc.) that were collected.

Moreover, for traffic sources, EMISENS model [8] - an emission inventory model for traffic activities (on-road mobile sources) was applied. Figure 2 shows the input requirements and output of the model. It calculates emissions from three emission stages: hot emission (E_hot), cold emission (E_cold), and evaporation emissions (E_evap) as in Eq. (2).

\[ E = E_{\text{hot}} + E_{\text{cold}} + E_{\text{evap}} \]  

In which cold emissions happen when the engine is in a warming up period and hot emission is considered when the engine reaches a stable heat period. Meanwhile, evaporation emissions are generated mainly from different temperature between the engine and the environment as running losses, hot soak, and and diurnal losses [8].
Figure 1. Research diagram of this study

Figure 2. EMISENS modeling method for road traffic air emission inventory

Vehicles are divided into five types as heavy-duty vehicles (HDV) with a total gross weight of over 3.5 tonnes, light duty vehicles (LDV) which weigh less than 3.5 tonnes, buses/coaches’ cars (<15 seats), and motorcycles. Meanwhile, streets were classified into five categories: highways, rural roads, urban streets, suburban streets, and industrial streets (which are located in the industrial zone). Emission factors for each emission stage, road type, and vehicle type could be easily modified when running the model which allow you to adopt EFs that suit the current traffic condition. Besides, vehicle brakes and road surface friction emission are also taken into account. In this study, EFs were taken from CORINAIR.

For non-road mobile sources, bus stations, airports, railways, and harbours were found in HCMC. A streamlined air emissions inventory approach was used following US EPA guidelines. This study inherits emission from Bang’s results [2].

Table 1. Source classification in HCMC

| EMISSION    | Point source | Industry            |
|-------------|--------------|---------------------|
| Area source | Household, Restaurants |                   |
| Line source | On-road and, vehicle brackes and road surface friction |       |

2.2 Meteorological and Air Quality Modelling

2.2.1 Meteorological model

The Air Pollution Model (TAPM) was developed by Commonwealth Scientific and Industrial Research Organization - Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia. TAPM is a three dimensional Eulerian meteorological model for simulating the meteorology. Detail
descriptions of the model were described by [10]. The model is non-hydrostatic and anelastic using a terrain following grid with finite volume discretization [11]. There are four domains from D1 to D4 including: (i) D1 is 800km x 800km (with 40 x 40 grids and the grid resolution was 20km), the outermost domain D1 characterizing the south of Vietnam; (ii) D2 is 400km x 400km (with 40 x 40 grids and the grid resolution was 10km), the wider domain D2 characterizing Mekong Delta; (iii) D3 is 200km x 200km (with 40 x 40 grids and the grid resolution was 5km), the domain D3 characterizing HCMC and some neighboring provinces; (iv) and D4 is 100km x 100km (with 40 x 40 grids and the grid resolution was 2.5km), the subdomain D4 characterizing the main part of HCMC. In which the three outer domains (D1, D2, D3) were meteorological simulation only and the inner domain (D4) was both meteorological and chemical simulation. The size of the inner-most domain (D4) was set to be the same as the HCMC emission inventory domain. The meteorological grids must be greater or equal to the emission grids; therefore, the emission inventory domain was set 90 km by 90 km with 35 grids and the grid resolution was 2.5 km.

2.2.2 Air quality model
The air quality model used in this study is the Chemical Transport Model (CTM). The model was developed by CSIRO and detail description model by document of The Centre for Australian Weather and Climate Research [12]. For simulations which require complex chemical transformation, CSIRO developed an enhanced version of TAPM referred to TAPM-CTM [12]. The advances of TAPM-CTM compared to TAPM analyzed thoroughly in the study of Bang, 2018 [13] in which the prognostic model provides the meteorological fields that drive dispersion of emissions and pollutant concentrations CTM.

2.2.3 Input data
Two components to input data of TAPM – CTM modeling system include: (i) the global meteorological data from The Australian Community Climate and Earth-System Simulator (ACCESS) which are available online and can be downloaded from CSIRO ftp site ftp://ftp.csiro.au/TAPM/SYNOPTIC_DATA/, and (ii) air emission inventory data within the region under consideration.

2.3 Model Evaluation
Similar to other models, TAPM and CTM model also need to be evaluated before using. This approach was used by comparing the observations from the field with the modeled data. In which meteorological data at Tan Son Hoa station and air quality data at Nguyen Van Cu station were used to assess the TAPM and CTM model, respectively. More specifically, statistical parameters including Pearson correlation coefficient (R) between observed and predicted values, mean value, standard deviation, minimum value (min), and maximum value (max) were used in this study. The results show that the TAPM and CTM model can simulate the meteorology and air for HCMC.

3. Results
3.1. Air emission inventory
The result states that the emission of PM$_{2.5}$ is 3,978.32 tons in 2017, as presented in Figure 3 below. Overall, the main emission sources in HCMC are on-road mobile, industry, and household source. In which transportation responsible for 45%, point source 32%, and 32% for area source of the main total in HCMC. Each of the main emission source includes many small sources, the detail of emission is described in Table 2. Among that, motorcycle is responsible for 18% of total on-road, 14% of vehicle brakes and road surface friction, and 14% of household of emission total in the city.
For mobile source, emissions mainly departed from on-road sources with major contributor was motorcycles. Due to the great number of vehicles, motorcycles released the most amount of PM$_{2.5}$ while heavy trucks, light trucks, and cars showed negligible amount of air pollutants. Industries contributed a great amount of total PM$_{2.5}$ (32%). The main sectors that generated great amount of air pollution were textile (13%), food (6%), paper production (4%), the remaining industries, each occupying about 1% of total emissions. Area sources account for the lowest proportion of total emissions. Households made up an important to PM$_{2.5}$ (14%) (Table 2). Next, restaurant activities contributed 14%, construction works and pagodas were with 1%.

Table 2 below describes the main sources of emission and its share according to small sources. Based on this, abatement strategies of technology and solution would be offered in order to reduce emissions of a specific pollutant, as follow: (i) For traffic source, motorcycle is the main source of emissions in traffic activities, reducing the number of motorcycles on the road will significantly reduce pollution from this source; (ii) For point source, building automatic monitoring to be continuously monitor the PM$_{2.5}$ load to the atmosphere form the chimneys of factories; (iii) For area sources: convert fuel used from charcoal, coal to clean energy such as wind energy, renewable energy form residential activities.

| Point source         | Area source     | Line source               |
|----------------------|-----------------|---------------------------|
| Textile              | Household       | Motorcycle                |
| Food                 | Restaurant      | Car                       |
| Paper production     | Constructions   | Light truck               |
|                      | work            |                           |
| Basic chemicals      | Pagodas         | Heavy truck               |
| wood production      |                 | vehicle brakes and road   |
|                      |                 | surface friction          |
| Beer, alcohol,       |                 | Harbor                    |
| beverage             |                 |                           |
Iron, steel and mechanical activities 2%
Plastic production 2%
Other activities 3%

3.2. Modeling results
3.2.1. Calibration and validation model
The model was calibrated from January 31, 2015 to February 4, 2015 for meteorology modeling at Tan Son Hoa station, found the advection coefficient equal 0.8 [2]. The model gives the results closest to reality with the observed temperature and simulation temperature having $R^2$ coefficient = 0.96 (Figure 4). To validate the TAPM model, need to two important parameters are surface temperature and wind speed. Results of the validation of the TAPM model at Tan Son Hoa show that simulation generated reliable data (Figure 5) with the correlation coefficient ($R^2$) not less than 0.7. The average temperature difference between the simulated temperature and the observed temperature in June 2017 is 1.4°C, in December 2017 is 0.7°C. The standard deviation value and the maximum temperature value are nearly the same with the difference of not more than 1°C, only the minimum value of December is 3°C. The highest wind in June and December 2017 is 1.5 m/s and 0.4 m/s, respectively. Other input coefficients were also changed, however, there is not much difference between these scenarios.

Figure 4. Temperature modeling with monitoring in 31/01/2015 – 04/02/2015
Figure 5. Temperature modeling with monitoring in June 2017
Air quality simulation results from the CTM model have been calibrated and verified with observed values at the Ho Chi Minh City University of Sciences located at 227 Nguyen Van Cu Street (10.762549°N, 106.682428°E). The data is measured continuously with 1 sample/hour during the period from June 12, 2017 to June 17, 2017 all give good results. With correlation coefficient (R²) between simulation and observed by the hour is greater than 0.6 (while this required value of R² is 0.6 as a model with good simulation capacity) [13]. Results of the validation of the CTM model at Nguyen Van Cu show that simulation generated reliable data (Figure 6).

Figure 6. CTM model validation

3.2.2. Simulation of PM$_{2.5}$ in HCMC in 2017
After the calibration and validation model, a simulation of the air quality for each hour in 2017 was conducted to determine the areas and duration having a high concentration of pollutants. The simulation results included all of one-hour, twenty four-hour, and annual average maximum concentration of PM$_{2.5}$. The average maximum of 1 hour of PM$_{2.5}$ is presented in Figure 7. With a concentration about 146 μg/m$^3$ at 08:00 AM on 12th December 2017, the highest concentration pollution in District 1, District 4, and Binh Chanh District. In the dry season from November to February next year, the main wind direction is Eastern and Northeast will push PM$_{2.5}$ from the center to the Western and Southwest districts of the city. Because the average hourly concentration of PM$_{2.5}$ is not regulated by QCVN 05:2013/BTNMT and the WHO’s guideline, this study does not have a basis for comparison.
The simulation results show that the PM\textsubscript{2.5} concentration pollution in the city has the highest average 24 hours with a concentration of 43.5 μg/m\textsuperscript{3} on 12\textsuperscript{th} December 2017 in the center of District 1, District 3, District 5, Binh Chanh, and some southwest districts of the city (Figure 8). The highest 24-hour average concentration of PM\textsubscript{2.5} is lower than QCVN 05: 2013/BTNMT (average 24 hours for PM\textsubscript{2.5} is 50 μg/m\textsuperscript{3}), but it exceeds WHO’s guide more than 1.7 times (average 24 hours for PM\textsubscript{2.5} is 25 μg/m\textsuperscript{3}).

![Figure 7. Average maximum 1 hours PM\textsubscript{2.5} concentration](image)

**Figure 7. Average maximum 1 hours PM\textsubscript{2.5} concentration**

A map of simulating annual average PM\textsubscript{2.5} generated by extracting the results from these 8760 hours. Emissions are most concentrated in the urban, where densely populated, the amount of traffic in this area is also the most. The average concentration in this area is about 20.4 - 23.0 μg/m\textsuperscript{3}. The average annual of PM\textsubscript{2.5} concentration in 2017 does not exceed QCVN 05:2013/BTNMT, but it has 1.2 to 2.3 times greater than WHO’s guideline. The results of this study also agree with other studies of Bang et.al [2]. Therefore, the PM\textsubscript{2.5} in HCMC impacts on public health of HCMC. To control and manage the air’s quality and minimize the generation of PM\textsubscript{2.5} in HCMC there are possible solutions such as the control of waste from the main source, the creation of encouraging policy, the regulation of air waste in HCMC, and the raising people’s awareness of environmental protection. From this simulation map, it can be used to serve future research such as counting PM\textsubscript{2.5} deaths on lung, cardiovascular, ischemic cancers, etc.

**3.3. Abatement strategies**

Table 2 describes the causes of air pollution in the city and its share according to source emission. This study proposed three groups of measures for improving air quality in HCMC:

**3.3.1. Solutions for environment manager**

Source reduction and waste minimization: Personal vehicles, especially motorcycles, are the biggest cause of pollution, accounting for about 18% of total sources. Therefore, reducing the number of motorcycles on the road will reduce air pollution significantly. Some specific measures are: Air smoke checking automobile randomly on road, Air smoke checking for motorcycles, Developing project for public transportation, Bike sharing system, Inspection outdate motorcycles and remove.

Combine many elements in the emissions control: Research results show that PM\textsubscript{2.5} emissions are mainly concentrated in urban areas, but it is affected by the blowing wind, so neighboring provinces are also
polluted. Therefore, it is necessary to control interprovincial and interregional to achieve the highest efficiency. Each waste source also generates many different pollutants except PM$_{2.5}$, it is necessary to develop an integrated emissions map of pollutants and emission zoning of air quality in HCMC.

Policy development for air quality control and management: The promulgation of legal documents and reasonable policies will be very effective in controlling and managing air pollution in Ho Chi Minh City, specifically, issuing guidance on emissions sources, with mechanisms encourage production facilities to renew technology, apply cleaner production, use clean fuels in production to reduce emissions, and at the same time develop a separate emission management plan for HCMC.

Building an automatic environmental monitoring system to be able to monitor PM$_{2.5}$ load of factories and households.

Application of Artificial Intelligence (AI), Big Data (Big Data), and Internet of Things (IoTs) in air quality management: every means of transport, chimney of factories are assigned an identifier, the emissions data are transferred to the environmental monitoring agency for management. Therefore, PM$_{2.5}$ emissions will be controlled, exceeding QCVN 05:2013 to the surrounding air environment.

3.3.2. Technology solutions
To progress to building a developed industry that still meets the goal of environmental protection, ensuring the ability to thoroughly tackle air pollution with the following technical: Promote the application of cleaner production technologies to prevent and minimize source pollution in the plant's production activities such as saving input fuel sources, replacing raw materials, and polluted fuels, with raw materials, cleaner fuel... Increase investment in technical solutions such as: innovating production technology, improving technical equipment to reduce emissions from sources into the environment. For traffic sources, the optimal solution is using renewable energy as fuel for traffic activities. Using renewable energy or clean energy such as wind, solar energy, electricity, natural gas for bicycles, electric motorcycles, electric cars or natural gas vehicles, energy vehicles solar, wind energy... is about green traffic.

3.3.3. Zoning solutions
It is obvious that if HCMC does not have a good plan to develop the social and economics, the air pollution situation in this city will become worse. Determining the pollutant loading capacities for each small area could help policy-makers to improve efficiency in building the abatement strategies. From the simulation results of air quality, areas were zoned by comparing with the QCVN. For areas with lower concentrations than QCVN, we increased the emission for each grid until to meet the standard. For areas with higher than QCVN, we reduced the emission for each grid until to meet the standard. In the calculation process, we also took into account the long-range transport based on the meteorological simulation results. For example, if the polluted area (A) was caused by emissions from the neighboring area (B), the B area would be diminished the emissions to reduce pollutant concentration at A area. We also considered the ability to increase emissions at A to determine whether the pollutant concentration in this area to increase or not.

3.3.4. Green space planning
Most of the current urban planning projects in Vietnam do not have appropriate spatial planning to ensure the goal of both economic development and a healthy living environment for the people, so the study has some Green space solutions for HCMC:

a. Establish a green belt around HCMC to limit widespread urban development with a policy of permanent land retention that cannot be used by urban development. The green belt creates a buffer zone for the development of agriculture, forestry and outdoor entertainment, ensuring the connection between urban and rural areas, protecting the natural or semi-natural environment, and where there are can help improve air quality in urban areas through the photosynthesis of trees.

b. Forming an urban green space system: properly arranged green space in an urban structure will increase the landscape and reduce urban air pollution. To form urban green space, the following factors will have a great influence such as the relationship between the construction land and the urban space; the proportion of existing green spaces, their number and location in an urban design structure, size and
detail of each green space, their roles and functions, landscape features, accessibility of traffic and pedestrians [14]. In which, the green space factor already exists in the city is the basic factor. Based on this factor, the urban green space system has 6 basic layouts that can be applied to HCMC as follows:

(i) Type of green space strip including a system of parks, flower gardens, open spaces combined with river water surface is the main layout axis in urban architectural space;

(ii) Combination form of natural elements scattered within the urban boundaries to form green space lines, towards the urban center;

(iii) Green space system is arranged centrally in the urban core area;

(iv) Green space system arranged in the form of a belt (circle or half circle) 01 or 02 layers surrounding the urban area;

(v) The green space system consists of one or more green space lines running in rows, along construction areas of urban centers or mixed with the same urban area;

(vi) Green space mixture system of the above 5 types.

4. Discussion
In recent years, the air quality in HCMC has been polluted by PM$_{2.5}$, and in the future, the air quality will become worse if we haven’t appropriated mitigation measures. This is the first comprehensive study on PM$_{2.5}$ emissions inventory and air quality TAPM – CTM modeling in HCMC, providing a specific look at the recent status of air quality to support the authorities to promulgate plans and actions to reduce emissions.

In this study, trans-boundary air emissions from other cities were not considered. Further research should include air emission sources from outside HCMC as Binh Duong, Long An, Tay Ninh, Binh Phuoc, etc. provinces because the transmission of pollutants in the air is influenced by the wind. In addition, to control and manage air quality effectively, it is necessary to synthesize many different pollutants to create a map of the overall pollution situation of the city.

Uncertainty in air emission inventory: most of the emission factors used to calculate the air emissions for industrial activities are taken from the EMEP/EEA Air Pollution Emission Inventory Guidebook 2016. Other emission factors for traffic sources as buses, light truck and heavy truck are taken from the COPERT IV [15]. The local emission factors in Vietnam are very limited. Some local emission factors for motorcycles and car ares used in this research. Proposing the management agencies to soon issue the emission inventory guidelines for use exclusively for Vietnam so that the next studies can use and give high accuracy results. Besides, vehicles are only count of HCMC, vehicles from other provinces have not been included in this study and similarly, the population is only calculated by statistics from the 2017 statistical yearbook of HCMC.

5. Conclusions
Detailed air emission inventory from 3 main sources showed that HCMC load 3,978.32 tons PM$_{2.5}$ into the atmosphere in 2017. From the actual PM$_{2.5}$ emissions, the study applied TAPM - CTM models to propagate simulation to map air pollution transmission, considering the influence by meteorology. The results after simulation show that the average maximum 1 hours, average for 24 hours and annual average of PM$_{2.5}$ concentration in 2017 does not exceed QCVN 05:2013/BTNMT, but it has 1.2 to 2.3 times greater than WHO’s guideline. Therefore, PM$_{2.5}$ has affected people's health.

The study has proposed solutions to reduce air pollution in Ho Chi Minh City, includes 4 main groups: solutions for managers, technical solutions, zoning solutions, and green space planning. Most importantly, raising the awareness of air environmental protection is the responsibility and meaning for each person.
From the above research results, the author remarks that the PM$_{2.5}$ pollution problem is alarming, it can still be controlled and minimized if we take appropriate measures. Well control emissions at source, implement waste discharge zoning to determine the load capacity of each pollutant for each area and redistribute industries with appropriate emissions according to the planned area, will create a fresh, clean air HCMC towards sustainable development in the near future.

**Author Contributions:**
B.Q.H contributes as coordinator for whole research, air quality modeling and develop abatement strategies. P.L.V was responsible for developing research methodology. K.T.D.N collected data, performed the validation of the models and prepared this manuscript. While H.N.K.V., T.T.T.N., and H.T.T.N. were responsible for calculating PM$_{2.5}$ emissions. H.N.K.V. is in charge of running TAPM-CTM model. T.T.T.N. contributed to the overview and discussion tasks. The manuscript was developed, revised, and edited by B.Q.H., P.L.V and H.N.K.V.

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