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Modeling of Air Pollution and Assessing Impacts of Air Pollution on Human Health: Tra Vinh, Vietnam

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Abstract

By the year 2023, Tra Vinh province will operate four coal – fired power plants (CFPP), which will release significant amount of air emissions. This study evaluates the intergrated effects of the four CFPP at the Tra Vinh Thermal Power Center on ambient air quality, thereby proposing measures to protect air quality in the area application a model system of meteorology and air quality (TAPM-CALPUFF). Besides, the objectives of this research are:

a) Assessing the effect of air pollution from Duyen Hai 1 and Duyen Hai 3 in operating to local public health;

b) Assessing the effect of air pollution from Duyen Hai 2 and Duyen Hai 3 extended in operating to public health for three diseases: lung cancer, Cardio – pulmonary and ischemic heart disease (IHD).

The simulation results of air pollution dispersion for 4 scenarios are calculated in the condition that the air treatment system is operating normally and efficiently, the results of pollutants are almost lower than Vietnamese standards (QCVN 05:2013), but only SO_2 is slightly higher than standard (1.3 times higher than standard, and happening only 2 hours / year). In the case of air pollution treatment systems of four power plants were not in operating, the affect to ambient air and to human health were very seriously as the highest average hourly concentrations of NO_2 and SO_2 exceeded the standard of 8.4 and 11.8 times, respectively. Dust also exceeds allowed standards. This study also pointed out that in current situation when Duyen Hai 1 and Duyen Hai 3 in operation, the number of people die due to air pollution ($PM_{2.5}$) from coal power plants were 03 and estimated the effects of air pollution caused by the other two thermal power plants (Duyen Hai 2 and Duyen Hai 3 extended) to public health, showing that air emissions from these two plants barely has no influence to public health. Therefore, in 2021 when all four power plants in operation with maximum capacity, the effect of air pollution (considering three main pollutants $PM_{2.5}$, NO_2 and SO_2) from power plants to public health will responsible for 04 deaths.

Keywords: Air emissions; CALPUFF model; Coal – fired power plants (CFPP); Health; TAPM model; Tra Vinh province.

Introduction

In the coming time, according to the adjusted Power Plan 7 of Vietnam, The Mekong Delta will have 14 coal-fired power plants up to 2030 with total capacity of 18,224MW. Although these electricity centers must have an Environmental Impact Assessment before construction, there are no studies have assessed the total effects of these plants to the environment as well as the human health since air pollution is claimed as "silence killer". Therefore, within the framework of cooperation between the Institute for Environment and Resources (IER) and the Green Innovation Center (GreenID), with the support of the European Climate Foundation (ECF) and GreenID on the implementation of the project " Contributing to the efforts of the Vietnam Sustainable Energy Alliance (VSEA) in promoting sustainable energy alternatives to coal thermal power in Vietnam, we conducted a study on " Modeling of air pollution and assessing impacts of air pollution on human health: Tra Vinh, Viet Nam "with the objective of assessing the effect of the Duyen Hai power center on the air quality of the area around the plant and Tra Vinh province, assessment of the impact of air pollution from these thermal power plants to community health with main pollutants from coal-fired thermal power plants such as SO_2, NO_2, CO, TSP and PM_{10}, $PM_{2.5}$, simulate air pollution for these substances using the TAPM-CALPUFF modeling system guided by experts from Harvard University, USA and then giving proposals for solutions as well as recommendations to planners and centers to develop a plan to protect air quality in the region.

Research Methods and Data

Emission calculation methodology

Emission calculation based on emission factor: The mass emission rate of a pollutant *i* from industry is calculated by a common formula [1]:

$$E_i = (A * EF_i / 1,000) * (100 - ER) / 100$$

Where:

E_i: Emission of pollutant *i* released from the point source (ton/year);

A: Activity data of emitters (tons of fuel/year applied to thermal power generation or tons of products/year applied to industrial facilities);

EF_i: Emission factor of pollutant *i*; kg/ton (activity data)

ER: Emission control efficiency of pollutant *i* (%), in case the facility does not have a control system,

ER = 0

Calculate air emissions of NOx, SO_2, CO, Dust, PM_{10} and $PM_{2.5}$: calculation based on emission factor from formula based on fuel consumption and fuel type using at four CFPP. The emission factor is referred from the three most important and famous sources because Vietnam hasn't emission factor for the coal-fired power plant, from the US EPA's emission factor AP42. WHO [2] and European EMEP/EEA [3,4]. All these emission factors depend on the type of coal and coal burning technology.

TAPM – CALPUFF model

TAPM model

In this study, the TAPM model was used to run the meteorological method in detail, taking data from the Australian meteorological monitoring center as an input. This method is also recommended for use by professionals from Harvard University. The simulation data was then calibrated and verified with meteorological data at My Cam station, Cang Long station, Tra Vinh province.

The TAPM model is a model of Australia's Commonwealth Scientific and Industrial Research Organization (CRISO). This model is used to predict meteorological conditions and atmospheric concentrations in three dimensions. So the model can be used as a meteorological aid for pollutant dispersion models, especially the meteorological input file for models of air quality models. This function has also been improved for TAPM V4 version when it integrates surface and meteorological meteorological formats by altitude. As a second function, air pollution simulations are modeled on the Lagrangian granular model, which can be applied to a variety of sources such as point sources, traffic, and biological sources. photochemical reaction conditions, catalytic reaction of water vapor, dry and wet deposition, gravity deposition. The model specifications are described in detail in the Model's Technology article (Hurley, 2008). The model uses terrain data, land and crop types, sea surface temperatures and meteorological conditions for a wide range of countries and regions. Since August 2010, TAPM is available worldwide for meteorology (except for bipolar).

Although TAPM has the function of simulating air pollution, however, it is quite simple and does not take into account the interaction between pollutants and no simulated dust and $PM_{2.5}$ function, so in this study only considers the use of a meteorological simulation module and, in addition, uses a specialized model to simulate air pollution, the CALPUFF model, which is recommended for use by Harvard University researchers.

The meteorological model set up with the grid center is the location of the thermal power plant, simulated for the whole year 2017.

Results of calibration and validation model

The meteorological station at My Cam, Cang Long, Tra Vinh province (Latitude 9°59' and Longitude 106°12') is the only national meteorological station in Tra Vinh province) started measure before 2007. The results between the monitoring data and the simulation data are shown in the Figure 1 above, which shows that the simulation performance of the TAPM model is quite good with the correlation coefficient for January R^2 = 0.82 (Figure 1).

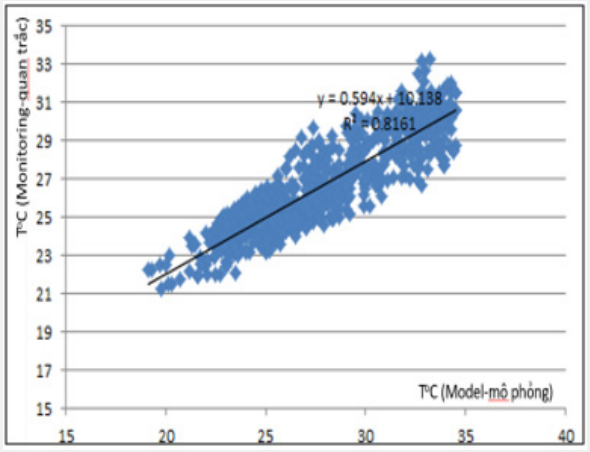

Figure 1: Correlation between simulation results and monitoring results for temperature at Cang Long station, Tra Vinh for January 2017.

Surface winds were also simulated by the TAPM model for the period of January 2017. The simulated results are compared with the meteorological monitoring data at My Cam station. The results show that the TAPM model has good performance for wind with average deviation (MB) 0.003 m/s (<± 0.5 m/s).

CALPUFF model

CALPUFF is an advanced model that integrates a Lagrangian beam simulator system to simulate the spread of airborne pollutants, investigated by the Atmospheric Research Team. This

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model is approved by the US Environmental Protection Agency and used in the Guidelines on Air Quality Models and used in the long-term assessment of the transport of pollutants and their effects to the Federal sector I.

The integrated modeling system consists of three main components and a set of preprocessing and postprocessing programs. The main components of the modeling system are CALMET (a diagnostic 3-dimensional meteorological model), CALPUFF (an air quality dispersion model), and CALPOST (a postprocessing package).

In this study, CALMET uses hourly meteorological data simulated by the TAPM model, data The CALMET output along with the data on emission scenarios is used as input to the CALPUFF model to simulate the diffusion of atmospheric substances. The CALPOST module is then run to calculate the conversion of NOx and SO2 to PM for the final simulation results.

Results of calibration and validation model

It is imperative to evaluate the dispersion model with observation data before using the simulated results, to check the input data and option for research area and the uncertainty of the model.

Mean Normalized Bias Error (MNBE):

$$MNBE = \frac{1}{N}\sum_{i=1}^{N}\frac{C_{\mathrm{mod}}\left(x_{i,t}\right)-C_{obs}\left(x_{i,t}\right)}{C_{obs}\left(x_{i,t}\right)}\times 100$$

Where

$C_{\mathrm{mod}}\left(x_{i,t}\right)$: modeling value at site i, time t

$C_{obs}\left(x_{i,t}\right)$: observed value at site i, time t

(Table 1) The data used to calibrate and verify the transmission air pollution model is the monitoring data in the monitoring.

Table 1: Standard of evaluation indicator.

Indicator	Standard
Mean Normalized Bias Error (MNBE)	± 15%

Source: US EPA, 2007.

The results of the MNBE error calculation between the simulated value and the average air quality monitoring value were 9.98% (ranging from 8.33% to 13.3%). This error is in the range of ± 15%. So, the CALPUFF model can simulate the spread of air pollution by the region. The next step is to use this model to simulate air pollution for different scenarios.

Health Impact calculation methodology

BENMAP [5] model (The Environmental Benefits Mapping and Analysis Program) (US-EPA, 2010): BenMAP ise used as a tool for estimating the human health effects and economic benefits associated with changes in ambient air pollution. The improvements in human health as a result of air pollution control regulations are typically referred to as the benefits of the regulations.

General equation to calculate impact of air pollution to human health (Shannon et al., 2017):

Health Effect = Air Quality Change * Health Effect Estimate * Health Baseline Incidence * Exposed Population (1)

Air Quality Change: the air quality change is the difference between the starting air pollution level, (i.e., the baseline), and the air pollution level after some change, such as a new regulation (i.e., the control).

Mortality Effect Estimate: The health effect estimate is an estimate of the percentage change in an adverse health effect due to a one unit change in ambient air pollution. Epidemiological studies provide a good source for effect estimates.

Mortality incidence: The health incidence rate is an estimate of the average number of people that die in a given population over a given period of time. For example, the health incidence rate might be the probability that a person will die in a given year. Health incidence rates and other health data are typically collected by the government. In addition, the World Health Organization is a good source for this.

Exposed Population: The exposed population is the number of people affected by the air pollution reduction. The government census office is a good source for this information.

Health data

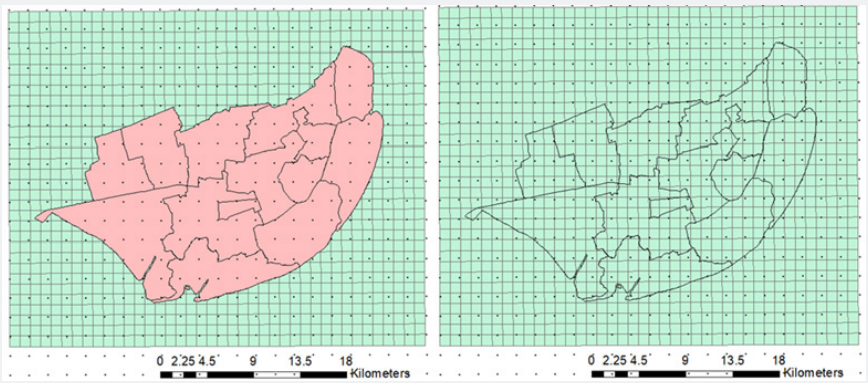

Figure 2: Domain for study area.

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Data on air pollution in each grid of the study area was extracted from the project results: "Simulation and assessment of air quality of Tra Vinh Thermal Power Center, Vietnam" for the study area. The district is Duyen Hai (14 communes, wards). Air pollution data are calculated for 3 substances $PM_{2.5}$, SO_2, NO_2 and for 2 scenarios: scenarios 1 (Duyen Hai 1 and Duyen Hai 3 thermal power plants operate) and scenarios 2 (Duyen Hai 1 and Duyen Hai 3 extended thermal power plants will operate in the future).

The data is calculated in each grid with a resolution of 1km x 1km, covering the whole of Duyen Hai District and Duyen Hai Town as shown in Figure 2.

Health Risk related to air pollution

The data on the epidemiological studies related to the effects of air pollutants on public health is refererived from the research report by Krewski [6] is "Extended Follow-Up and Spatial Analysis of the American Cancer Society Study Linking Particulate Air Pollution and Mortality", a study by Mike (Mike, 2014) is " Implementation of the HRAPIE Recommendations for European Air Pollution CBA work " and a study of WHO and EEA is "Health risks of air pollution in Europe – HRAPIE project: recommendations for concentration–response functions for cost–benefit analysis of particulate matter, ozone and nitrogen dioxide". The HRs shows in Table 2.

Table 2: Health risk ratio (HRs).

Covariate	MSA/Participants (n)	Incremental Change[b]	All Causes	Cardio-pulmonary	IHD	Lung Cancer	All Other Causes
$PM_{2.5}$ (1979-1983)	58	10μg/m³	1.03	1.06	1.12	1.08	0.98
	351,338		(1.01-1.04)	(1.04-1.08)	(1.09-1.16)	(1.03-1.14)	(0.96-1.00)
$PM_{2.5}$ (1999-2000)	116	10μg/m³	1.03	1.09	1.15	1.11	0.97
	499,968		(1.01-1.05)	(1.06-1.12)	(1.11-1.20)	(1.04-1.18)	(0.94-1.00)
SO_4^{2-} (1980)	147	5μg/m³	1.04	1.04	1.06	1.05	1.03
	572,312		(1.03-1.05)	(1.02-1.05)	(1.04-1.08)	(1.02-1.09)	(1.02-1.05)
SO_4^{2-} (1990)	52	5μg/m³	1.07	1.06	1.14	1.04	1.08
	268,336		(1.05-1.09)	(1.03-1.09)	(1.10-1.19)	(0.97-1.11)	(1.05-1.11)
SO_2 (1980)	115	5ppb	1.02	1.02	1.04	1	1.02
	513,450		(1.02-1.03)	(1.01-1.03)	(1.02-1.05)	(0.98-1.02)	(1.02-1.03)
PM_{15} (1979-1983)	57	15μg/m³	1.01	1.03	1.06	1	0.99
	345,824		(1.00-1.02)	(1.02-1.05)	(1.04-1.08)	(0.97-1.04)	(0.97-1.00)
TSP (1980)	152	15μg/m3	1	1.01	1.01	0.98	0.99
	578,704		(1.00-1.01)	(1.01-1.02)	(1.00-1.01)	(0.97-1.00)	(0.99-1.00)
O_3 (1980)	118	10ppb	1	1.01	1.01	1	0.99
	531,826		(0.99-1.01)	(1.00-1.03)	(0.98-1.03)	(0.96-1.04)	(0.97-1.00)
O_3 (Summer 1980)	118	10ppb	1.02	1.03	1.01	0.99	1.01
	531,185		(1.01-1.02)	(1.02-1.04)	(0.99-1.02)	(0.96-1.02)	(1.00-1.02)
NO_2 (1980)	76	10ppb	0.99	1.01	1.02	0.99	0.98
	406,917		(0.99-1.00)	(1.00-1.02)	(1.00-1.03)	(0.97-1.01)	(0.97-0.99)
CO (1980)	108	1ppm	1	1	1.01	0.99	0.99
	508, 538		(0.99-1.01)	(0.99-1.01)	(0.99-1.03)	(0.97-1.03)	(0.98-1.01)

[a]HRs are followed by 95% confidence intervals.

[b]Incremental change on which the HR is based: pollutant level.

Results and Discussion

Modeling of air pollution for normal case (air treatment system operates in good condition)

Run the CALPUFF air pollution transmission model with meteorological data from the TAPM model for 2017. The CALPUFF model and the TAPM model run for all 365 days * 24 hours / year = 8760 hours / day. The output of the excel file as well as the map is for each hour of 8760 hours / year.

The CALPUFF model data is mainly derived from the emission data in the above Table 2. And the surface and high meteorological data are not from the above TAPM model.

- Simulation for the following 04 scenarios [7-10]:

a) Only one Duyen Hai 1 thermal power plant operates,

b) Duyen Hai 1 and Duyen Hai 3 thermal power plants are operate (the current operating scenario),

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c) Duyen Hai 1 and Duyen Hai 2 and Duyen Hai 3 thermal power plants are operate,

d) Duyen Hai 1 and Duyen Hai 2 and Duyen Hai 3 and Duyen Hai 3 expand thermal power plants are operate (Scenario for 2023).

The results from the simulated transmission air pollution in the images below are the highest results for 1 hour, 24h and the average year on the ground.t. Then compare the simulated results with the allowable values of pollutants in the ambient air (QCVN 05:2013).

The simulation results for scenario 1

The simulated air pollution results for scenario 1 (Huyen Hai 1 thermal power plant only) shows that the maximum 1-hour concentrations, average 24h and the average annual for air pollutants $PM_{2.5}$, PM_{10}, TSP, NOx, SO_2 and CO are much smaller than QCVN 05: 2013.

The simulation results for scenario 2

The simulated dispersion of air pollution for Scenario 2 (Huyen Hai 1 thermal power plant and Duyen Hai 3 thermal power plant are operating) showed that the maximum 1 – hour concentration, average 24h and average annual for air pollutants $PM_{2.5}$, PM_{10}, TSP, NOx, SO_2 and CO are smaller than the QCVN 05 : 2013.

The simulation results for scenario 3

The maximum 1 – hour concentration, average 24h and average annual for air pollutants $PM_{2.5}$, PM_{10}, TSP, NOx and CO don't affect the ambient air environment. For SO_2, the average of SO_2 concentration for 24h (101.96µg/m^3) and the annual average (1,813µg/m^3) are very small compared to the QCVN 05: 2013 (for 24h (125µg/m^3) and annual average (50µg/m^3)).

The simulation results for scenario 4

The maximum 1 – hour concentration, average 24h and average annual for air pollutants $PM_{2.5}$, PM_{10}, TSP, NOx and CO do not affect the ambient air environment. For SO_2, the average of SO_2 concentration for 24h (112.16µg/m^3) and the annual average (2.19µg/m^3) are very small compared to the QCVN 05: 2013 (24h (125µg/m^3) and annual average (50µg/m^3)) (Figure 3 & 4).

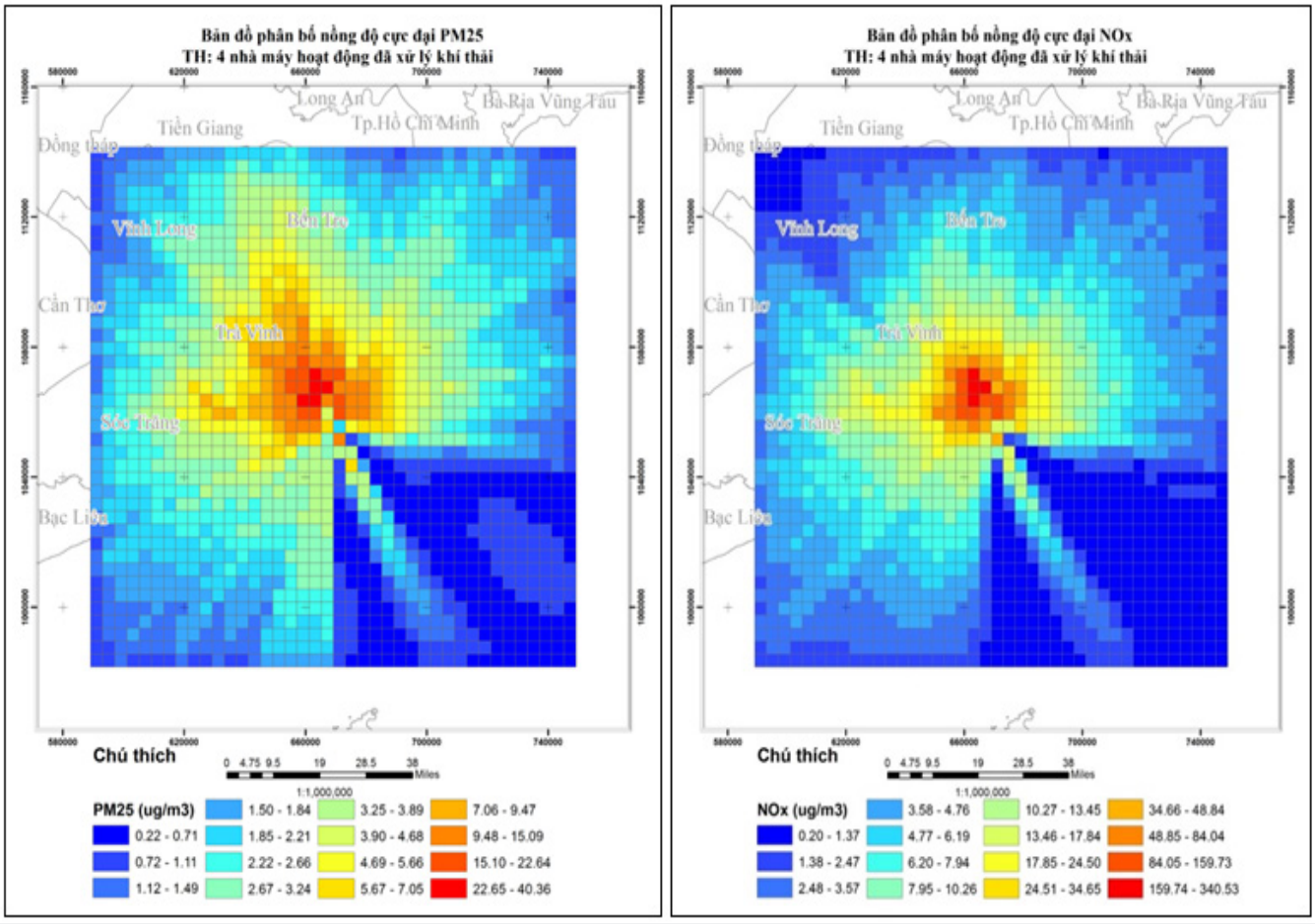

Figure 3: The highest average $PM_{2.5}$ and NOx (right) maps for one hour per year. Stages are different levels of concentration.

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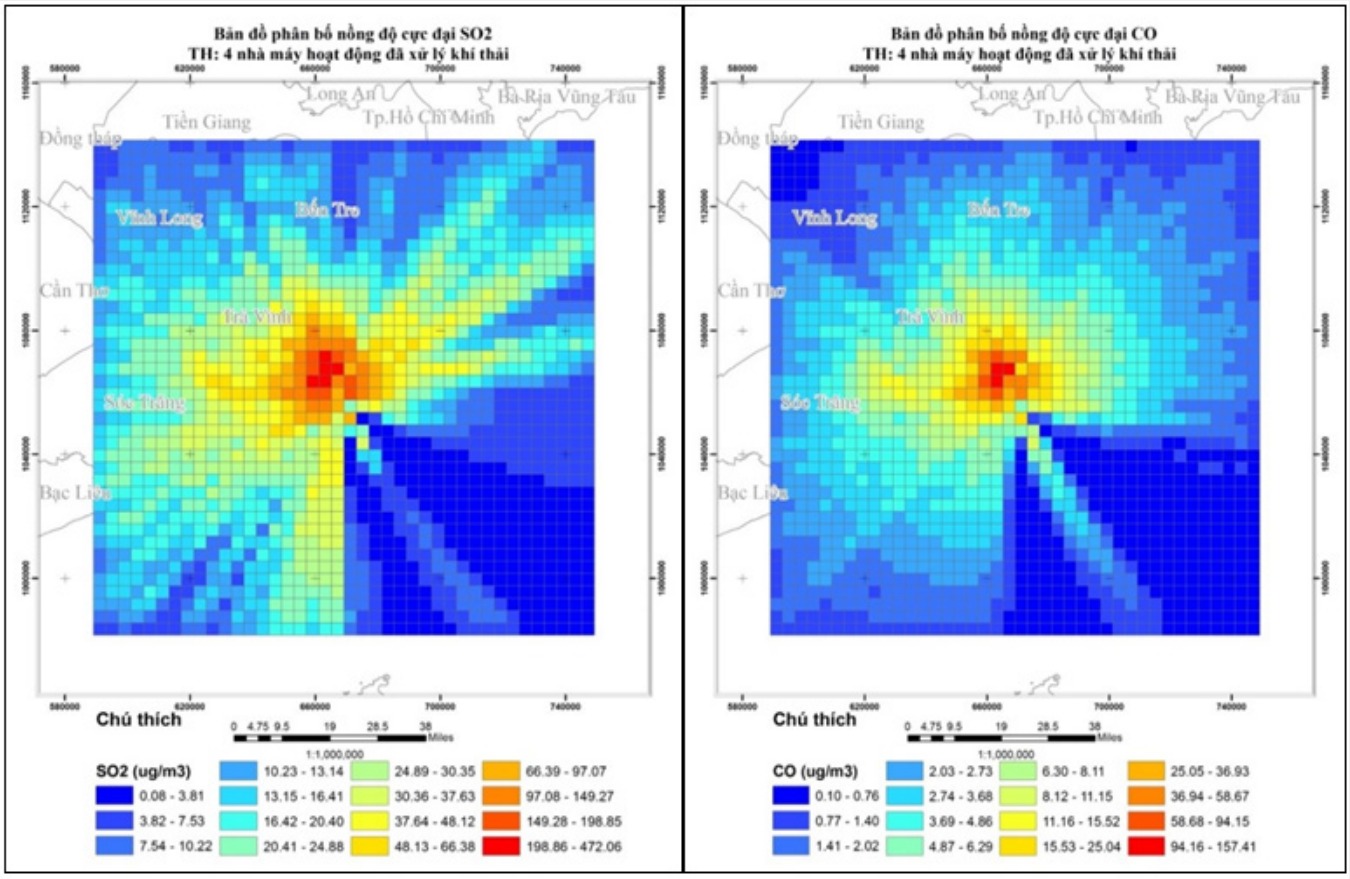

Figure 4: The highest average SO_2 and CO (right) maps for one hour per year. Stages are different levels of concentration.

Simulation for the case air treatment systems of 4 plants are accident (don't operate)

Simulation results for NOX

The highest average hourly result of the NOX in the North West direction of the Central Thermo Power Center is 1676μg/m^3, higher than QCVN 05: 2013 (200μg/m^3 allowed) about 8.4 times. Therefore, the exhaust system does not work then the pollution is huge.

Simulation results for SO_2

The highest average hourly result of SO_2 in the North West direction of the Central Thermo Power Center is 4117μg/m^3, higher than that of QCVN 05: 2013 (350μg /m^3 allowed). about 11.8 times. Therefore, the exhaust system does not work then the pollution is huge.

The simulation results for the highest $PM_{2.5}$ 1 hour

The average peak hour of $PM_{2.5}$ in the North West direction of the Central Thermo Power Center is very high at 2026μg /m^3. The highest average hourly rate of $PM_{2.5}$ is about 6.8 times higher than the TSP standard average (QCVN 05: 2013 allowable is 300μg/m^3) (because TSP includes PM_2 dust. 5). Therefore, the exhaust system does not work then the pollution is huge.

Calculation impact of air pollution on Human Health

Results of $PM_{2.5}$ impact on lung cancer

Duyen Hai 1 thermal power plant and Duyen Hai 3 thermal power plant operate (recently)

(Figure 5) The calculating result of the impact of $PM_{2.5}$ from two operating thermal power plants (Duyen Hai 1 and Duyen Hai 3) to community health in Figure 5 shows that the number of deaths from lung cancer is very small about 0.2 cases per year. The calculating result of the impact of P.M $_{2.5}$ from two thermal power plants in planning (Duyen Hai 2 and Duyen Hai 3 are expanded) to community health.

The calculating result of the impact of $PM_{2.5}$ from two operating thermal power plants (Duyen Hai 1 and Duyen Hai 3) to community health in Figure 5 shows that the number of deaths from Cardio-Pulmonary is very small about 02 cases per year. The calculating result of the impact of P.$M_{2.5}$ from two thermal power plants in planning (Duyen Hai 2 and Duyen Hai 3 are expanded) to community health in Figure 5, shows that almost $PM_{2.5}$ from these two plants is not fatal because of Cardio-Pulmonary.

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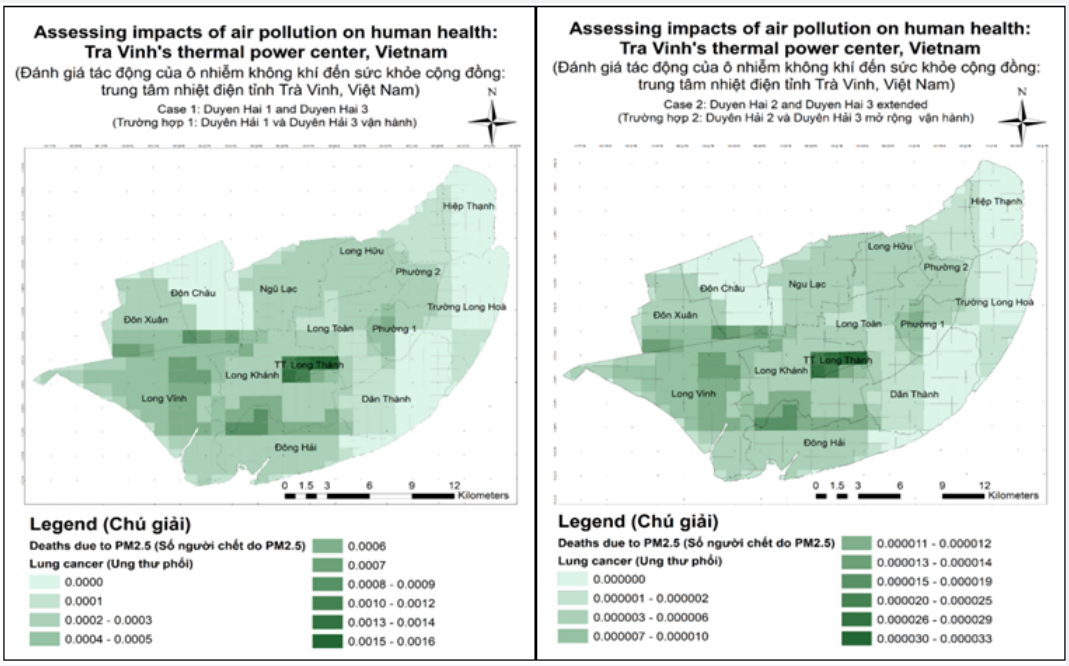

Figure 5: Map of associated deaths with lung cancer due to $PM_{2.5}$ for Duyen Hai 1 and Duyen Hai 3 CFPP (left) and Duyen Hai 2, Duyen Hai 3 expend (right). Color scales are different levels mortality.

Total deaths due to $PM_{2.5}$, NO_2 và SO_2

Table 3 shows the effects of air pollution from 4 thermal power plants on community health. The results show that the operating thermal power plants (Duyen Hai 1 and Duyen Hai 3 thermal power plants) using high ash domestic coal emit $PM_{2.5}$. This is the cause of death of about 2 cases per year due to Cardio-Pulmonary disease and 01 case per year due to IHD disease. NO_2 and SO_2 are less impact to the community health.

Table 3: Synthesize the effects of air pollution from 4 thermal power plants on community health for one year (unit: case).

Plant	Pollution	Cardio-Pulmonary	IHD	Lung Cancer	Total
1&3	$PM_{2.5}$	2	1	0.2	3.2
	NO_2	0.03	0.02	0.002	0.05
	SO_2	0.32	0.14	0.02	0.48
2 & 3 mởrộng	$PM_{2.5}$	0.06	0.02	0.003	0.08
	NO_2	0.004	0.002	0.0003	0.01
	SO_2	0.06	0.03	0.01	0.1
Total					4

The plants in the construction plan (Duyen Hai 2 thermal power plant and Duyen Hai 4 thermal power plant) are going to use imported coal with low ash, therefore it can reduce $PM_{2.5}$ emission. This is not fatal for people in Duyen Hai district [10-34].

Conclusion

Results of air pollution simulations for the four scenarios which is calculated under the conditions of the air pollution treatment system operating normally and effectively, are as follows:

The simulated air pollution results for scenario 1 (Huyen Hai 1 thermal power plant only) shows that the maximum 1-hour concentrations, average 24h and the average annual for air pollutants $PM_{2.5}$, PM_{10}, TSP, NOx, SO_2 and CO are much smaller than the QCVN 05: 2013.

The simulated dispersion of air pollution for Scenario 2 (Huyen Hai 1 thermal power plant and Duyen Hai 3 thermal power plant are operating) showed that the maximum 1 – hour concentration, average 24h and average annual for air pollutants $PM_{2.5}$, PM_{10}, TSP, NOx, SO_2 and CO are smaller than the QCVN 05 : 2013.

The simulated dispersion of air pollution for Scenario 3 (Huyen Hai 1, Duyên Hai 2 and Duyen Hai 3 thermal power plants are operating) showed that the maximum 1 – hour concentration, average 24h and average annual for air pollutants $PM_{2.5}$, PM_{10}, TSP, NOx and CO don't affect the ambient air environment. For SO_2, the average of SO_2 concentration for 24h (101.96μg/m^3) and the annual average (1,813μg/m^3) are very small compared to the QCVN 05: 2013 (for 24h (125μg/m^3) and annual average (50μg/m^3)). However, the result of the maximum 1-hour SO_2 concentrations in the Northwest the center is 432.17μg/m^3 which is higher than the QCVN 05: 2013 (350μg/m^3). The maxiumum 1-hour concentration of SO_2 is higher than the QCVN 05: 2013 about 1.23 times. Only 2 hours per year (8760 hours/year) exceeds this standard. The area exceeds the standard is 1.92km^2. In addition, the average concentration for 24h and the annual

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average are very small compare to the QCVN 05 2013, so it can be concluded that this concentration of SO_2 has almost no effect on the environment.

The simulated dispersion of air pollution for Scenario 4 (Huyen Hai 1, Duyên Hai 2, Duyen Hai 3, and Duyen Hai 3-expansion thermal power plants are operating) showed that the maximum 1 – hour concentration, average 24h and average annual for air pollutants $PM_{2.5}$, PM_{10}, TSP, NOx and CO do not affect the ambient air environment. For SO_2, the average of SO_2 concentration for 24h (112.16µg/m^3) and the annual average (2.19µg/m^3) are very small compared to the QCVN 05: 2013 (24h (125µg/m^3) and annual average (50µg/m^3)). However, the result of the maximum 1-hour SO_2 concentrations in the Northwest the center is 472.06µg/m^3 which is higher than the QCVN 05: 2013 (350µg/m^3) about 1.3 times. Only 2 hours per year (8760 hours/year) exceeds this standard. The area exceeds the standard is 1.93km^2. In addition, the average concentration for 24h and the annual average are very small compare to the QCVN 05 2013, so it can be concluded that this concentration of SO_2 has almost no effect on the environment.

For the purpose of recommending and identifying the risk of air pollution, the simulation results for case that when all four plants operate together and the exhaust gas treatment system is not working, the air pollution is very serious. Specifically, the highest average hourly concentrations of NO_2 and NO_2 exceeded the standard of 8.4 and 11.8 times, respectively. Dust also exceeds the standard.

Calculated impact of air pollution caused by 2 thermal power plants operating Duyen Hai 1 and Duyen Hai 3 of Tra Vinh Thermal Power Center to public health as follows:

The thermal power plants are operating (Duyen Hai 1 and Duyen Hai 3 thermal power plants) use high ash domestic coal to produce $PM_{2.5}$. This is the cause of death of about 2 cases per year due to Cardio-Pulmonary disease and 01 case per year due to IHD disease.

NO_2 and SO_2 are not nearly cause any mortality in the community.

The study also estimated the effects of air pollution caused by the two thermal power plants that will operate Duyen Hai 2 and Duyen Hai 3 to expand to public health as follows: the plants in the construction plan (Duyen Hai 2 thermal power plant and Duyen Hai 4 thermal power plant) are going to use imported coal with low ash, therefore it can reduce $PM_{2.5}$ emission. This is not fatal for people in Duyen Hai district.

In 2021, four thermal power plants will operate at maximum capacity, the potential for air pollutants ($PM_{2.5}$, NO_2 and SO_2) effect to public health. Four deaths per year (2.5 cases due to cardio-pulmonary disease, 1.2 cases due to IHD and 0.3 cases due to lung cancer).

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