Assessing the air quality, toxic and health impacts of the Van Phong 1 coal-fired power project in Vietnam

Lauri Myllyvirta, lead analyst, Greenpeace Global Air Pollution Unit | April 2019

Summary

Coal-fired power plants are among the largest sources of air pollutant emissions in Vietnam, contributing to 4,300 premature deaths in 2011 (Koplitz et al 2017). The proposed Van Phong 1 project would significantly increase air pollutant emissions from power generation in central Vietnam, with potentially substantial impacts on air quality and public health.

This case study provides a detailed analysis of the air quality, toxic and health impacts of the proposed Van Phong 1 coal-fired power plant, combining detailed atmospheric modeling with existing epidemiological data and literature.

The emissions from the studied power plant elevate the levels of toxic particles and NO_2 in the air over a large area, increasing the risk of diseases such as stroke, lung cancer, heart and respiratory diseases in adults, as well as respiratory infections in children. This leads to premature deaths from these causes. SO_2, NOx and dust emissions contribute to toxic particle exposure. Emissions from the plant cause acid rain, which can affect crops and soils, as well as fallout of toxic heavy metals such as arsenic, nickel, chrome, lead and mercury.

The emissions from the studied coal-fired plant would be likely to result in approximately 60 premature deaths per year due to exposure to PM2.5 and NO2 (95% confidence interval: 30-90 deaths). Over an operating life of 30 years, this would mean approximately 1,900 premature deaths.

The emissions from the studied power plant would expose an estimated 20,000 people to SO2 concentrations exceeding the WHO guideline for 24-hour average concentration, before considering any other emission sources in the region. This exposure carries a significant risk of acute respiratory symptoms, especially for vulnerable groups such as children, elderly people and people with pre-existing respiratory ailments.

Mercury deposition from the plant is projected to exceed levels which can cause health risks, over an area with 11,000 inhabitants. In total, approximately 15kg of mercury per year is projected to be deposited on land as a result of emissions from the power plant.

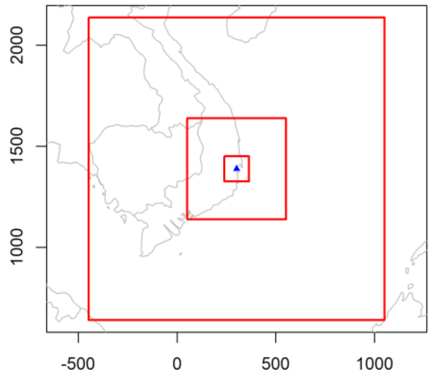

Figure 1 Calpuff modeling domains (red) and location of the studied power plant project (blue triangle).

Air pollutant emissions

Basic information on the studied power plant project was collected from the Environmental Impact Assessment (EIA) report. The emission mass flow data (g/s) provided in the EIA was inconsistent or erroneous, so emission rates were estimated from stack emission concentrations (mg/Nm3) given for each pollutant and flue gas flow rate estimated from power plant data and coal composition data given in the EIA. Flue gas volume per heat input (Nm3/GJ) was calculated based on the formulas of Neavel (1986) for gross calorific value, ISO 1928-2009 for difference between gross and net calorific value, and EN12952-15 for flue gas volume per kilogram of fuel.

The flue gas pollutant concentrations given for the plant are multiple times higher than international best practice, which greatly exacerbates the impacts.

Data on mercury emissions was completely missing from the EIA so emissions were estimated using the default parameters for sub-bituminous coal in the UNEP mercury toolkit (2017).

Table 1. Flue gas flow

Parameter	Value	Unit	Basis
Thermal capacity	3030	MW	EIA
Fuel higher heating value	5978	kcal/kg	Calculated from coal composition in EIA, based on Given (1986)
Fuel lower heating value	5653	kcal/kg	Calculated from coal composition in EIA, based on ISO 1928-2009
Fuel specific flue gas volume	6.059	Nm3/kg	Calculated from coal composition in EIA, based on EN12952-15
Fuel specific flue gas volume	359	Nm3/GJ	Calculated from above
Flue gas flow	**1087.8**	**Nm3/s**	Calculated from above

Table 2. Pollutant flue gas concentrations

Parameter	SO2	NOx	Dust	Unit
Flue gas concentration	300	360	47	mg/Nm3

Table 3. Emission input data for dispersion modeling

Parameter		Value	Unit	Source
Stack characteristics	Longitude	109.1780	degrees	EIA
	Latitude	12.5493	degrees	EIA
	stack height	240	m	EIA
	diameter	6.94	m	EIA
	exit temperature, K	315	K	EIA
	exit velocity, m/s	23.0	m/s	EIA
Emission rates at full operation	SO2	326.3	g/s	Calculated from EIA
	NOx	391.6	g/s	Calculated from EIA
	PM10	34.5	g/s	Calculated from EIA
	Full-load hours	6500	h/a	EIA
Mercury emissions	Coal use	3660000	t/a	EIA
	Coal Hg content	30.0	ppb	UNEP 2017
	Mercury removal efficiency	40%		UNEP 2017
	Mercury emissions	66	kg/a	Calculated

To establish short-term maximum air quality impacts, these full-operation emission rates were modeled for a full year. Annual air quality impacts and health impacts are assessed based on average plant operating rate projected in the EIA.

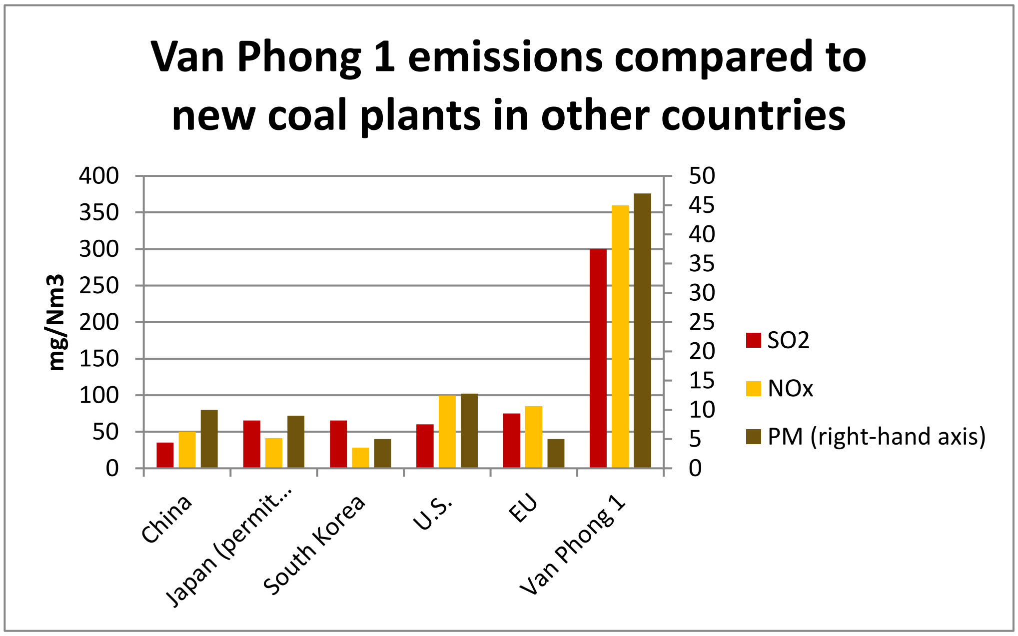

Figure 2 Emission levels of the studied power plant compared with legal limits in other jurisdictions

Impacts on air quality

Emissions from the power plant would affect air quality most significantly over a large area spanning approximately 100 kilometers northeast and southwest of the plant. In addition, there is a substantial amount of pollution transported northward along the coast. In the most affected locations, within 10-30km of the power plant to the north, west and south, maximum 24-hour SO2 concentrations caused by the emissions from the plant exceed the WHO guideline values.

The emissions from the studied power plant would expose an estimated 20,000 people to SO2 concentrations exceeding the WHO 24-hour guideline, before considering any other emission sources in the region. This exposure carries a significant risk of acute respiratory symptoms, especially for vulnerable groups such as children, elderly people and people with pre-existing respiratory ailments. The WHO guideline for 1-hour average NO2 concentration is also projected to be exceeded over a small area to the north of the power plant due to the emissions from the plant alone; when considering other emissions sources, exceedances can be expected over a much larger area.

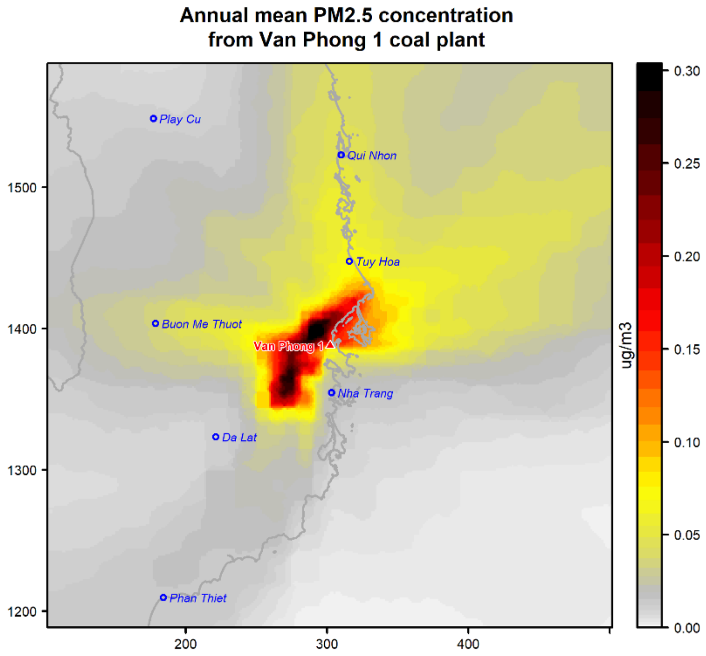
Annual mean PM2.5 concentration
from Van Phong 1 coal plant

Figure 3 Projected annual average PM2.5 concentration attributable to emissions from the Van Phong 1 coal power project

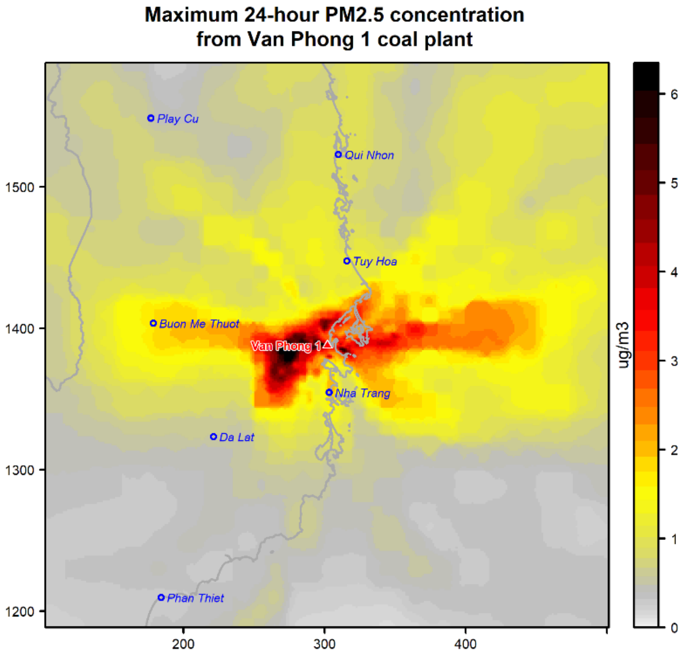

Figure 4 Projected maximum 24-hour PM2.5 concentration attributable to emissions from the Van Phong 1 coal power project

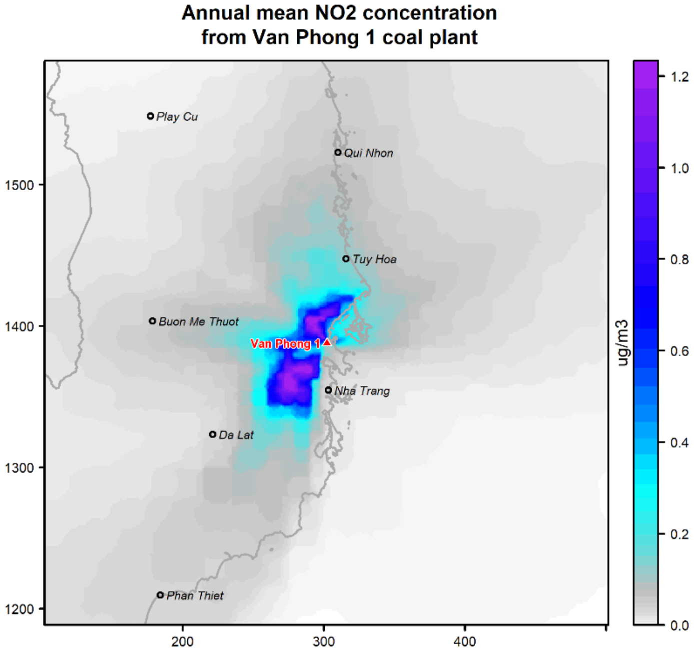

Figure 5 Projected annual average NO2 concentrations caused by emissions from the Van Phong 1 coal power project

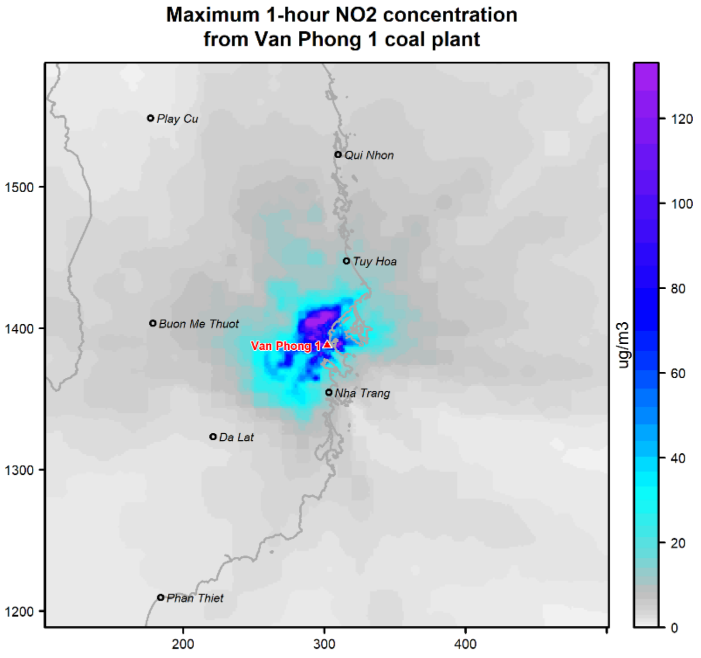

Figure 6 Projected 1-hour maximum NO2 concentrations caused by emissions from the Van Phong 1 coal power project

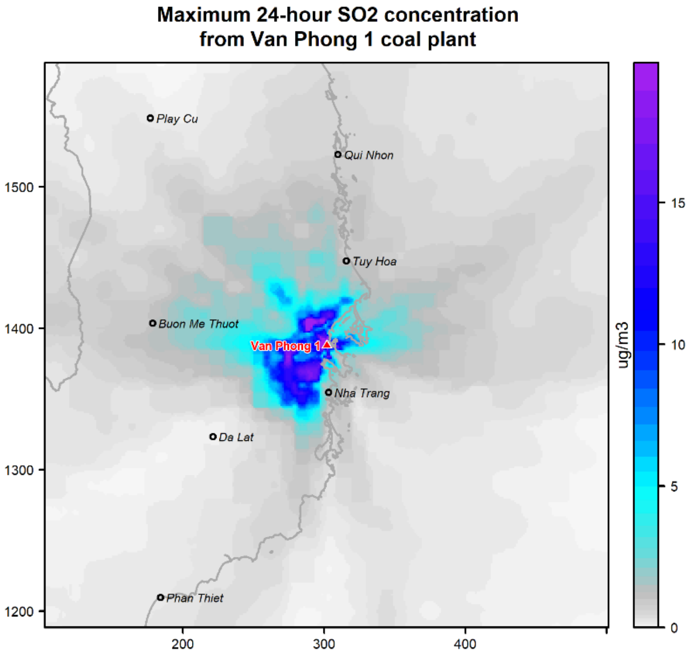

Figure 7 Projected 24-hour maximum SO2 concentrations caused by emissions from the Van Phong 1 coal power project

Health impacts

The emissions from coal-fired power plant project are likely to result in approximately 60 premature deaths per year due to exposure to PM2.5 and NO2 (Table 4) after plant commissioning (impacts modeled for population and projected health status in 2025). Over an operating period of 30 years, this would imply a total of approximately 1,900 premature deaths.

Table 4 Projected premature deaths and other health impacts caused by emissions from the Van Phong 1 coal power project, cases per year

Pollutant	Cause	Central	Low	High
PM2.5	Lung cancer	5	2	7
	Other cardiovascular diseases	4	2	5
	Ischemic heart disease	6	4	8
	Stroke	18	11	25
	Other respiratory diseases	2	1	2
	Chronic obstructive pulmonary disease	8	5	12
	Total	43	26	61
NO2	All causes	20	8	28
	Total	56	31	89

Toxic fallout

The pollution emissions from coal-fired power plants lead to deposition of toxic heavy metals, fly ash, acid rain and mercury (Figure 8, Figure 9 and Figure 10). The deposition mainly occurs during rains and in this region is consequently largest to the southwest of the power plant.

Of the 67kg/year of mercury estimated to be emitted by the plant, approximately 15kg or 1/5 is estimated to be deposited into land and freshwater ecosystems. Mercury deposition rates as low as 125mg/ha/year can lead to accumulation of unsafe levels of mercury in fish (Swain et al 1992). The plant is estimated to cause mercury deposition above 125mg/ha/yr over an area of approximately 50km2, in the northwest of the plant, with a population of 11,000 people (Figure 8). The majority of the projected deposition on land takes place into forest (44%) and cropland (37%). Deposition onto cropland is of particular concern, because rice paddy can produce methylmercury which is easily taken up by the rice plant (see e.g. Zhang et al 2010).

While actual mercury uptake and biomagnification depends very strongly on local chemistry, hydrology and biology, the predicted mercury deposition rates are certainly a cause for concern and for further study – it is unacceptable that this issue was entirely omitted in the Environmental Impact Assessment of the project.

Acid deposition could affect forests and other natural ecosystems. Farmers can see affected yields or increased input costs as they have to neutralize the deposition. Acid rain also damages property and culturally important buildings. Coal fly ash contains toxic heavy metals that are associated with a range of health risks. Most intense acid and fly ash deposition takes place to the southwest and north to northwest of the plant, with deposition in the most affected areas exceeding 20kg of SO2-equivalent per hectare per year in an area of approximately 160km2. (Figure 10). Fly ash deposition rates exceeding 5kg/ha/year are predicted in the vicinity of the plant in an area of approximately 50km2 (Figure 10).

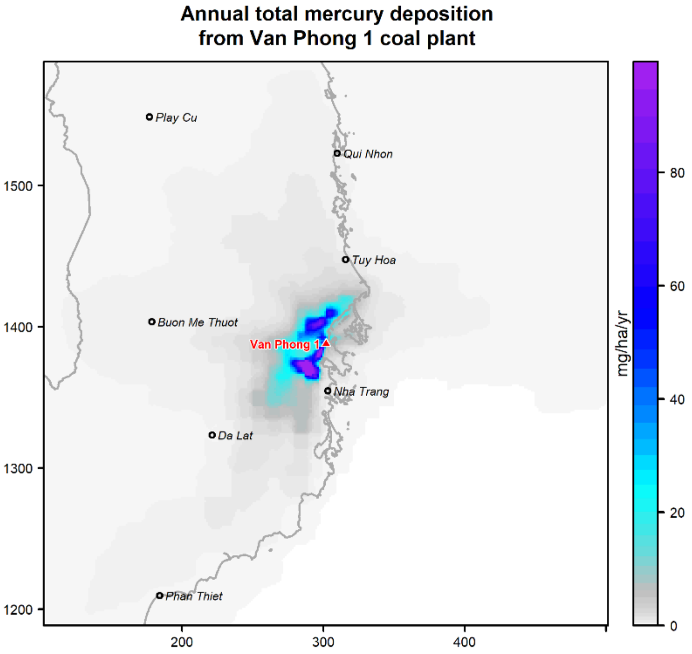

Figure 8 Projected mercury deposition from the Van Phong 1 power plant

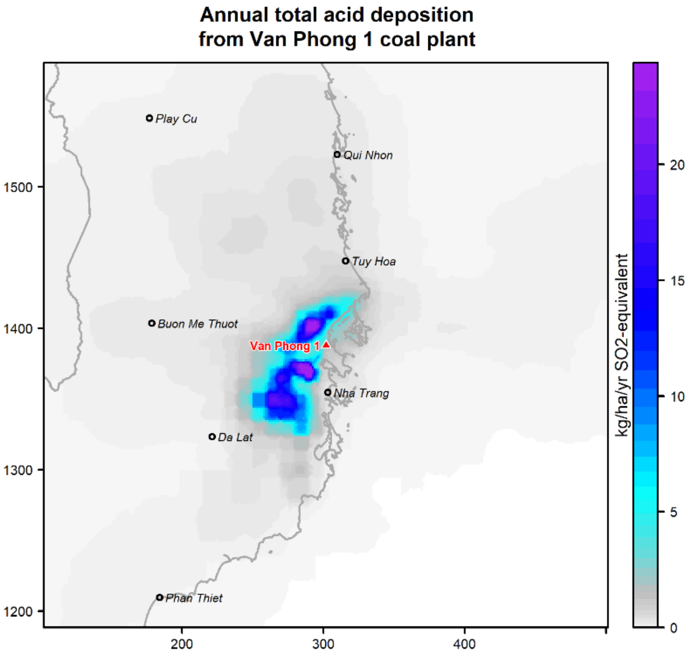

Figure 9 Projected acid deposition (SO2 equivalent) from the Van Phong 1 power plant

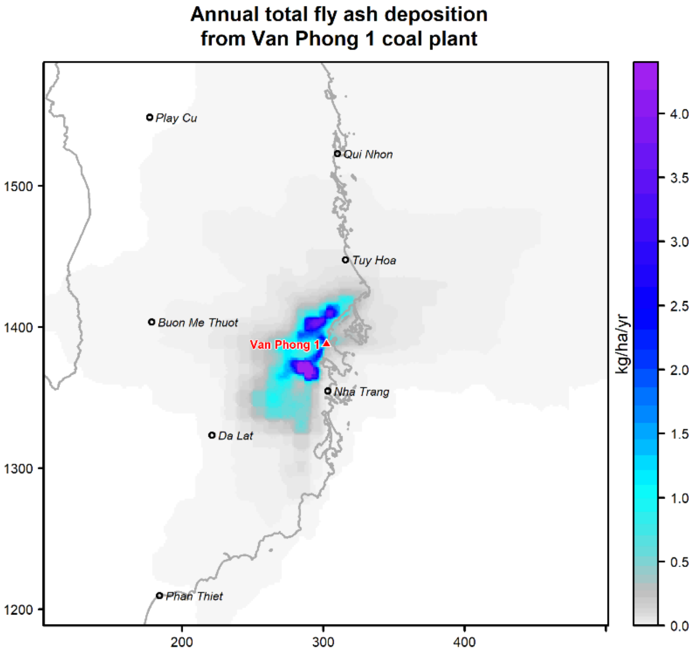

Figure 10 Projected fly ash deposition from the Van Phong 1 power plant

References

Anenberg SC et al, 2010. An estimate of the global burden of anthropogenic ozone and fine particulate matter on premature human mortality using atmospheric modeling. Environ. Health Perspect. 2010, 118 (9), 1189. https://ehp.niehs.nih.gov/0901220/

Center for International Earth Science Information Network (CIESIN), Columbia University, 2017. Gridded Population of the World, Version 4 (GPWv4): Population Density, Revision 10. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/H4DZ068D.

European Space Agency (ESA), 2018. Land Cover Maps – v2.0.7. http://maps.elie.ucl.ac.be/CCI/viewer/download.php

Given PH, D Weldon, JH Zoeller 1986: Calculation of calorific values of coals from ultimate analyses: theoretical basis and geochemical implications. Fuel 65(6):849-854. https://doi.org/10.1016/0016-2361(86)90080-3

Koplitz et al 2017: Bub;erden of Disease from Rising Coal-Fired Power Plant Emissions in Southeast Asia. Environmental Science & Technology. http://dx.doi.org/10.1021/acs.est.6b03731

Krewski D et al 2009: Extended Follow-Up and Spatial Analysis of the American Cancer Society Study Linking Particulate Air Pollution and Mortality. HEI Research Report 140. Health Effects Institute, Boston, MA. https://www.healtheffects.org/publication/extended-follow-and-spatial-analysis-american-cancer-society-study-linking-particulate

UNEP, 2017. Toolkit for Identification and Quantification of Mercury Releases. UN Environment Chemicals Branch, Geneva, Switzerland.

U.S. EPA 1998: AP-42: Compilation of Air Pollutant Emission Factors, Ed. 2, Fifth Edition, Volume I. https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors

World Bank (WB), World Development Indicators. http://databank.worldbank.org/data/home.aspx

World Health Organization (WHO), 2013. Health risks of air pollution in Europe-HRAPIE project. http://www.euro.who.int/__data/assets/pdf_file/0006/238956/Health_risks_air_pollution_HRAPIE_project.pdf?ua=1

World Health Organization (WHO), 2014. Global Health Estimates. http://www.who.int/healthinfo/global_burden_disease/estimates/en/index1.html

Zhang H et al, 2010. In Inland China, Rice, Rather than Fish, Is the Major Pathway for Methylmercury Exposure. Environ Health Perspect. 118(9): 1183–1188. https://dx.doi.org/10.1289%2Fehp.1001915

Appendix: Materials and methods

Atmospheric dispersion modeling for the case studies was carried out using version 7 (June 2015) of the CALPUFF modeling system. CALPUFF is an advanced non-steady-state meteorological and air quality modeling system adopted by the U.S. Environmental Protection Agency (USEPA) in its Guideline on Air Quality Models as the preferred model for assessing long range transport of pollutants and their impacts.

3-dimensional meteorological data for the simulations was generated using the TAPM modeling system, developed by Australia's national science agency CSIRO, and cross-validated against the observational data. TAPM uses as its inputs global weather data from the GASP model of the Australian Bureau of Meteorology, combined with higher-resolution terrain data. TAPM outputs were converted into formats accepted by CALPUFF's meteorological preprocessor, CALMET, using the CALTAPM utility, and the meteorological data were then prepared for CALPUFF execution using CALMET. CALMET generates a set of time-varying micrometeorological parameters (hourly 3-dimensional temperature fields, and hourly gridded stability class, surface friction velocity, mixing height, Monin-Obukhov length, convective velocity scale, air density, short-wave solar radiation, surface relative humidity and temperature, precipitation code, and precipitation rate) for input to CALPUFF.

Terrain height and land-use data were also prepared using the TAPM system and global datasets made available by CSIRO. A set of nested grids with a 50x50 grid size and 15km, 5km and 2.5km horizontal resolutions and 12 vertical levels was used, centered on each power plant.

For emissions from main boilers of the power plants, 30% of emitted fly ash was assumed to be PM2.5, and 37.5% PM10, in line with the U.S. EPA (1998) AP-42 default value for electrostatic precipitators. Particles larger than 10 microns were modeled with a mean aerodynamic diameter of 15 microns.

Chemical transformation of sulphur and nitrogen species was modeled using the ISORROPIA/RIVAD chemistry module within CALPUFF, and required atmospheric chemistry parameters (monthly average ozone, ammonia and H2O2 levels) for the modeling domain were imported into the model from baseline simulations using the Geos-Chem global atmospheric model with nested grid for Southeast Asia (Koplitz et al 2017). The CALPUFF results were reprocessed using the POSTUTIL utility to repartition different nitrogen species (NO, NO2, NO3 and HNO3) based on background ammonia concentrations.

The health impacts resulting from the increase in PM2.5 concentrations were evaluated by assessing the resulting population exposure, based on high-resolution gridded population data for 2015 from NASA SEDAC (CIESIN 2017), and then applying the health impact assessment methodology of the Harvard-Greenpeace coal-health study (Koplitz et al., 2017). In addition, premature deaths from NO2 exposure were assessed based on the recommendations of WHO (2013).Baseline death rates in Vietnam from different causes were obtained from WHO Global Health Estimates (2014), birth rates and incidence of low birth weight from World Bank (undated).

The fundamental equation used for projecting increases in health impacts, based on Anenberg et al (2010) is:

$$\Delta y_{ij} = y_{0ij}\left(1 - exp^{-\beta_i \Delta x_j}\right) p_j$$

where Δy is the change in mortality, y_0 is the baseline mortality, p is the population in the applicable age group, Δx is the change in concentration, i is the specific cause of mortality and j is the country. β is the coefficient in the regression equation of the effect estimate for the specific mortality cause:

$$RR = exp^{\beta \Delta X}$$

where RR is the risk ratio reported in the original study and ΔX is the concentration change for which the risk ratio is reported (see Table 5 for the RR values used).

Deposition results were differentiated by land use type using the European Space Agency global land use map for the year 2015 at 300m resolution (ESA 2018; see Figure 11). Land use codes 10-30 were mapped as cropland; codes 50-100 and 160-170 were mapped as forest.ta

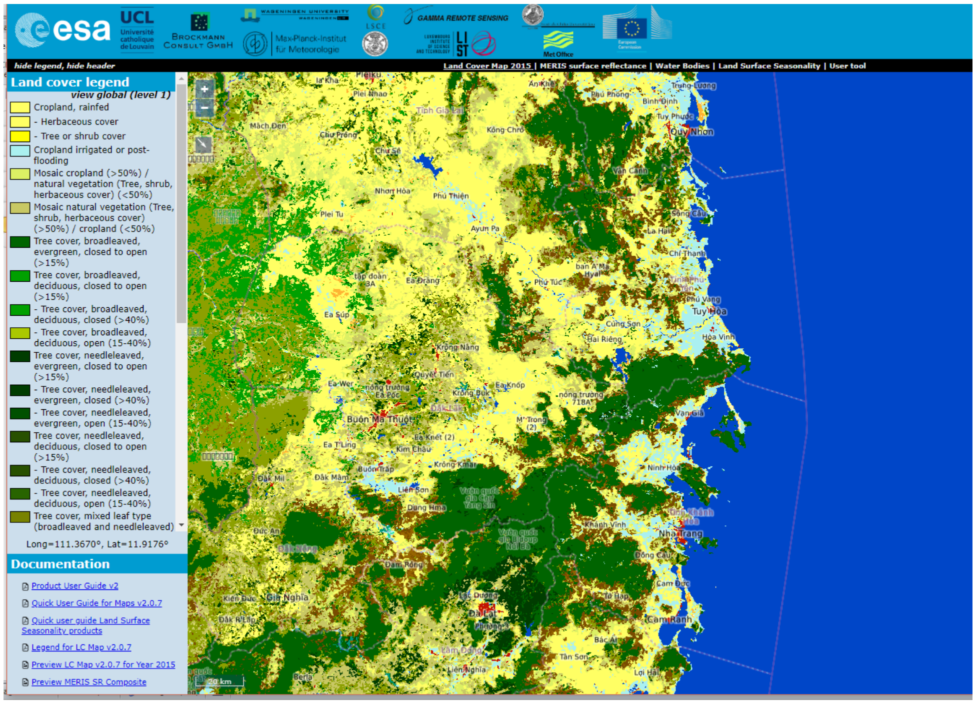

Figure 11 Land use map used for assessing deposition impacts (ESA 2018)

Table 5 Risk ratios from different studies used for health impact assessment

Risk ratio for 10µg/m³ increase in PM2.5 exposure	**Central**	**95% CI, low**	**95% CI, high**	**Reference**
Cardiopulmonary diseases	1.128	1.077	1.182	Krewski et al 2009
Ischemic heart disease	1.287	1.177	1.407	Krewski et al 2009
Lung cancer	1.142	1.057	1.234	Krewski et al 2009
Risk ratio for 10µg/m³ increase in NO2 exposure	**Central**	**95% CI, low**	**95% CI, high**	**Reference**
All causes[1]	1.055	1.021	1.08	WHO 2013

---

[1] *When calculating total health impacts, central and low values for NO2 are scaled down by 1/3 to remove possible overlap with PM2.5 impacts, as indicated in WHO (2013).*