Assessing the air quality, toxic and health impacts of coal-fired power plants surrounding the Jakarta megacity

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Summary

The existing coal-fired power plants in west Java, one of the most densely populated areas in the whole world, are among the largest point sources of air pollution in Indonesia, with potentially major impacts on the surrounding communities and ecosystems. A dramatic increase in coal-fired capacity in the area is planned, entailing the risk of much larger future impacts: if the proposed power plant projects are realized, Greater Jakarta will see more new coal-fired power stations built within 100 kilometres than any other capital city.

This case study provides a detailed analysis of the air quality and health impacts of these existing and proposed coal-fired plants within 100km of central Jakarta, combining detailed atmospheric modeling with existing epidemiological data and literature. The impacts were modeled over a 1500km x 1500km domain covering Indonesia and parts of the surrounding areas.

The emissions from the existing power plants in western Java

- Elevate the levels of toxic particles and NO_2 in the air over the entire region, including in the greater Jakarta (Jabotabedek) megacity, 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, NO_x and dust emissions contribute to toxic particle exposure.
- Cause acid rain, which can affect crops and soils.
- Cause fallout of toxic heavy metals such as arsenic, nickel, chrome, lead and mercury.

The planned expansion of coal-fired generation in the region would dramatically exacerbate these impacts, with the number of people exposed to $PM_{2.5}$ levels exceeding WHO guidelines, solely due to emissions from coal power plants, increasing from 3 million currently to 31 million.

Emissions from the currently operating coal-fired power plants result in an estimated 5,260 premature deaths and 1,690 low birth weight births per year due to exposure to $PM_{2.5}$ and NO_2. Taking future changes in population into consideration, constructing the planned coal-fired power plants would result in additional 5,420 deaths and 1,130 low birth weight births.

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The toxic mercury emissions from the operating power plants are estimated at 400 kilograms per year and projected to double to 800kg per year if the new plants come online. Modeled mercury fallout from the coal plant emissions onto Java and South Sumatra would increase from 170kg per year to 300kg per year, and the number of people living in areas where mercury fallout could potentially lead to accumulation of unsafe levels of mercury in fish would increase from an estimated 1.4 million to 4.3 million.

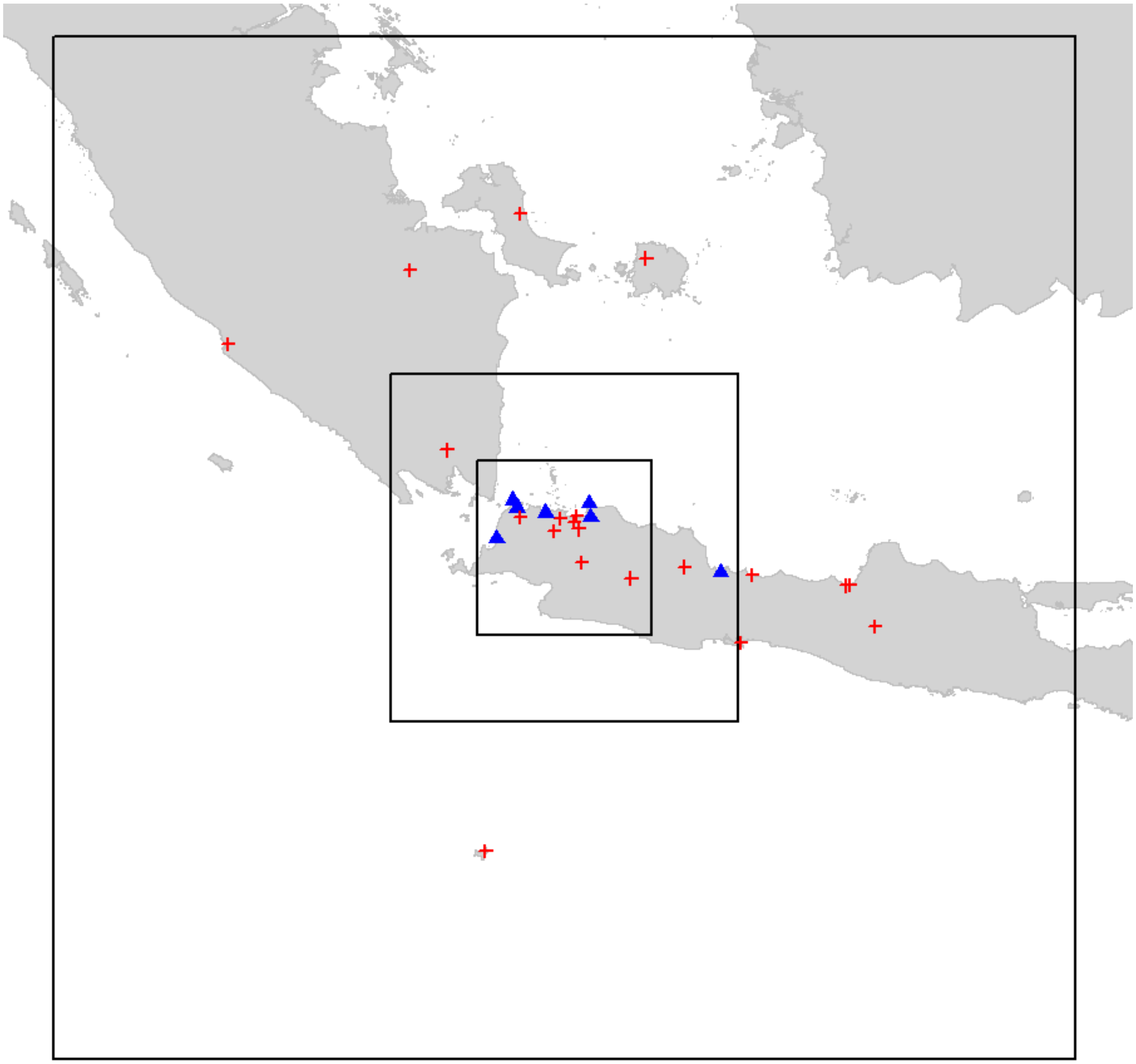


Figure 1 CALPUFF modeling domains (red), location of study area (blue triangle and location of different meteorological observations (green asterisk).

Air pollutant emissions

Annual emissions were calculated from emission rates at full operation given in the EIA, assuming 80% capacity utilization. The basic data on the location and stack characteristics of the plants were similarly obtained from the EIA and are shown in Table 2 below, and assumed for other similar units where data was missing. The emission data shown in Table 1 and Table 2 were used as the basis of modeling the plants' air quality impacts using the CALMET-CALPUFF modeling system. The modelling domains used is shown in Figure 1 above.

Table 1 Estimated air pollutant emissions from the power plants. Operating plants in black and new projects in red.

Units	Capacity, MW	Flue gas concentrations (mg/Nm^3)			Annual emissions (tonnes)			
		SO_2	NO_x	Dust	SO_2	NO_x	Dust	Mercury (kg)
PLTU Suralaya – Banten 1-4	1600	680	686	119	23,234	42,519	4,074	90
PLTU Suralaya – Banten 5-7	1800	680	686	119	26,138	43,999	4,583	101
PLTU Suralaya – Banten 8	625	680	686	100	9,904	9,995	1,457	38
PLTU Labuan 1-2 (PLTU Banten-2)	600	750	750	26	10,494	10,494	358	37
PLTU Teluk Naga (PLTU Lontar/PLTU Banten-3)	945	748	592	22	16,056	12,698	461	56
PLTU Cikarang Babelan	280	750	750	24	4,768	4,768	150	17
PLTU Pelabuhan Ratu	1050	750	750	100	17,881	17,881	2,384	63
PLTU Merak	120	750	750	100	2,044	2,044	272	7.2
Pindo Deli Pulp and Paper Mill II	50	750	850	100	851	965	114	3.0
PLTU Bojonegara	2000	750	750	24	29,414	29,414	924	103
PLTU Lontar Expansion	315	750	750	24	4,633	4,633	145	16
PLTU Banten Expansion (PLTU Jawa-9)	1000	750	750	24	15,408	15,408	484	54
PLTU Muara Gembong	2000	750	750	24	30,815	30,815	968	108
Lestari Banten Energi	670	750	750	50	10,323	10,323	688	36
Asahimas Chemical Plant	300	750	750	100	5,109	5,109	681	18
Existing units total	7070				111,370	145,363	13,854	412
New units total	7605				116,040	116,040	4,528	406

Table 2 Basic data on the case study power generating units.

Plants	Stack height, m	Stack inner diameter, m	Flue gas velocity, m/s	Flue gas temperature, C
PLTU Suralaya – Banten 1-4	200	5.5	21.5	72
PLTU Suralaya – Banten 5-7	275	6.5		
PLTU Suralaya – Banten 8	275			
PLTU Labuan 1-2 (PLTU Banten-2)	215	7.5		95
PLTU Teluk Naga (PLTU Lontar/PLTU Banten-3)	127	4.6	25	131
PLTU Cikarang Babelan	235	6.3	17.4	90
PLTU Pelabuhan Ratu	235	6.3	17.4	90
PLTU Merak	127	4.6	17.4	90
Pindo Deli Pulp and Paper Mill II	127	4.6	17.4	90
PLTU Bojonegara	235	6.3	17.4	90
PLTU Lontar Expansion	235	6.3	17.4	90
PLTU Banten Expansion (PLTU Jawa-9)	235	6.3	17.4	90
PLTU Muara Gembong	235	6.3	17.4	90
Lestari Banten Energi	235	6.3	17.4	90
Asahimas Chemical Plant	235	6.3	17.4	90

Impacts on air quality

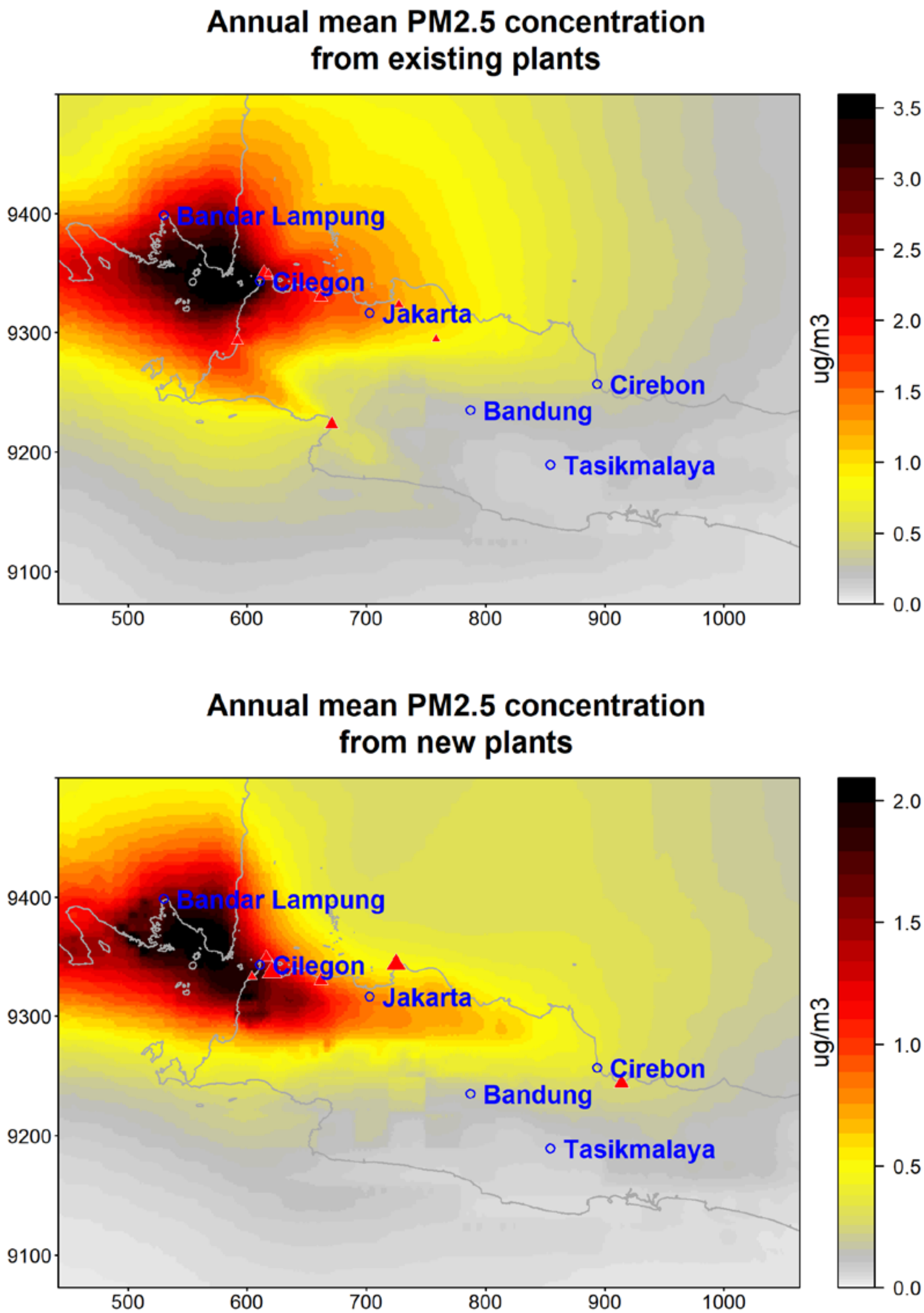
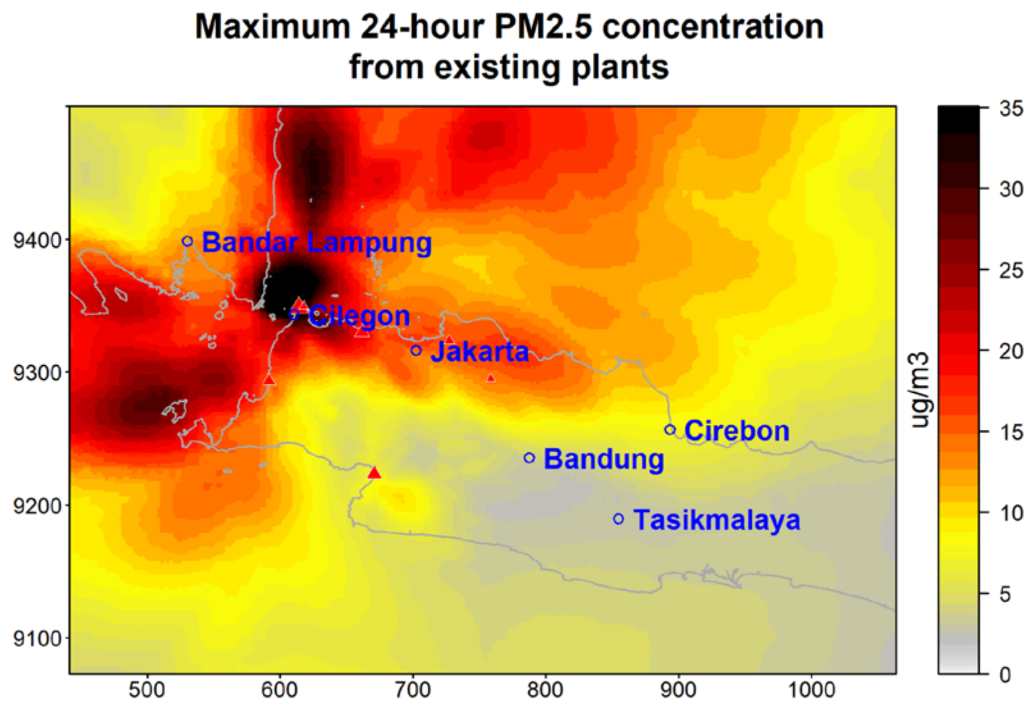


Figure 2 Projected annual average $PM_{2.5}$ concentration attributable to emissions from the existing power plants (top) and new power plants (bottom).



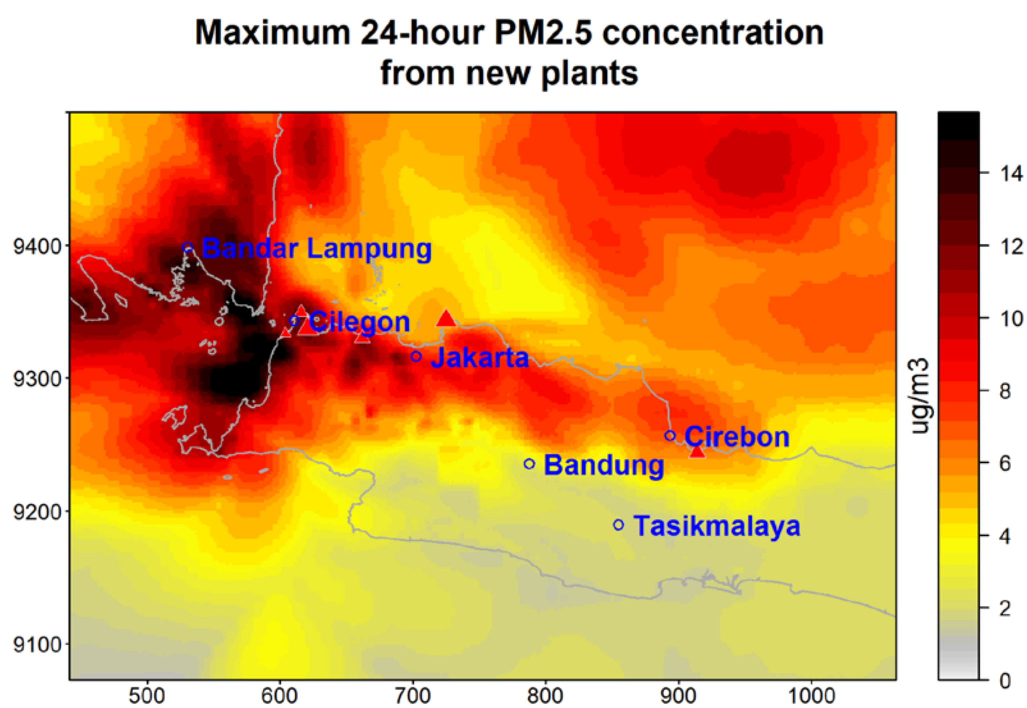


Figure 3 Projected maximum 24 hours $PM_{2.5}$ concentration attributable to emissions from the existing power plants (top) and new power plants (bottom).

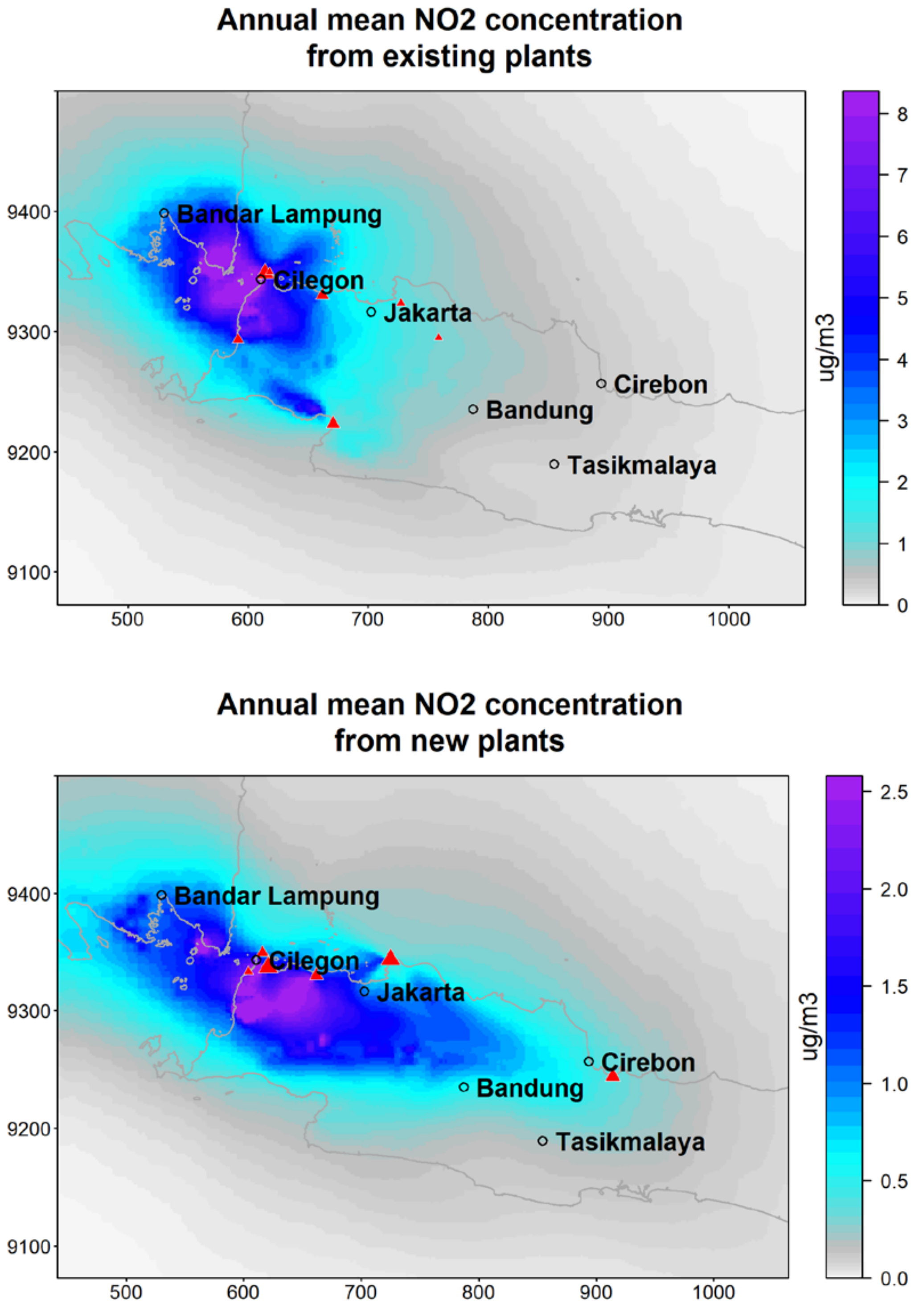


Figure 4 Projected annual average NO_2 concentrations caused by emissions from the existing power plants (top) and new power plants (bottom).

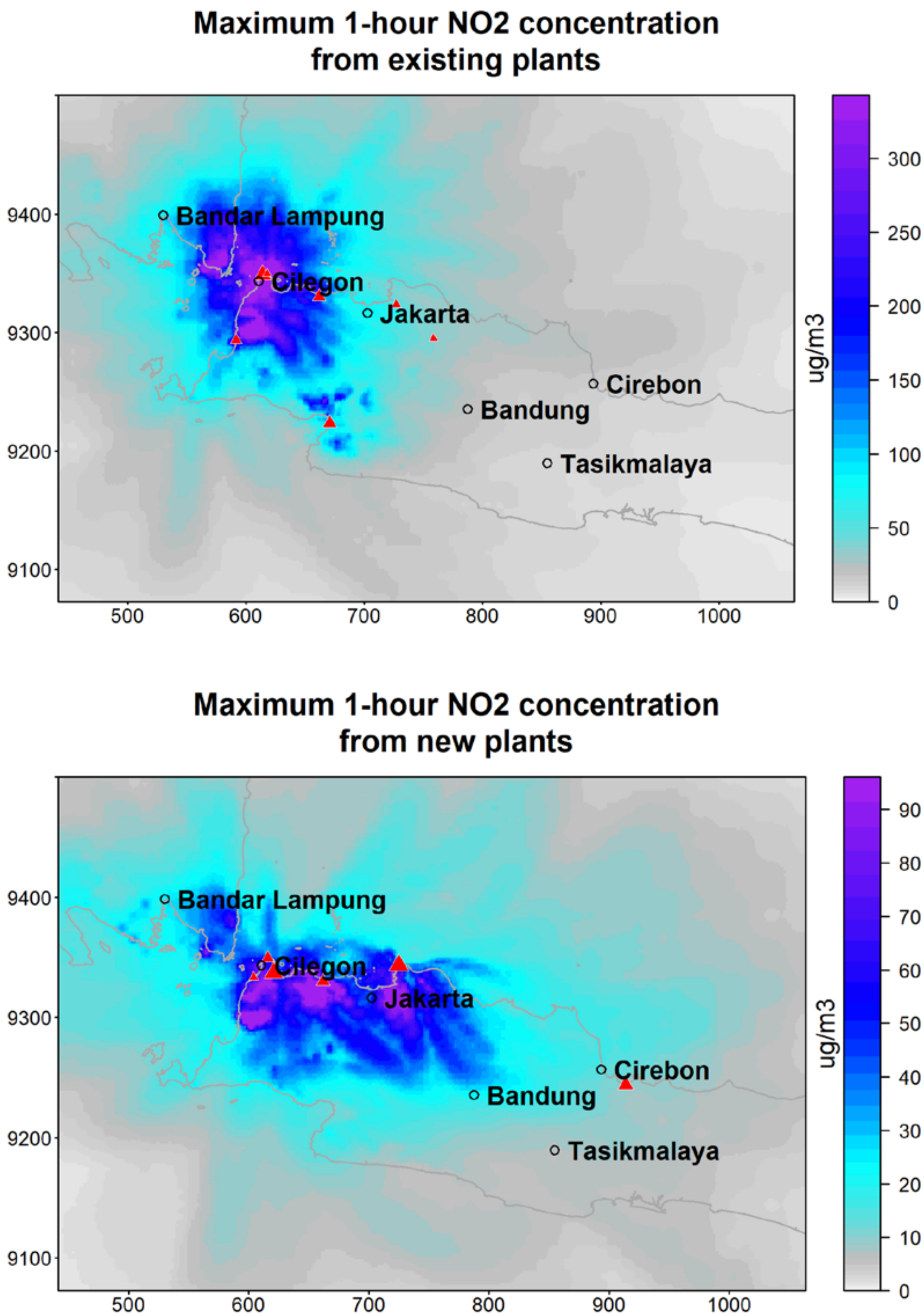


Figure 5 Projected 1-hour maximum NO_2 concentrations caused by emissions from the existing power plants (top) and new power plants (bottom).

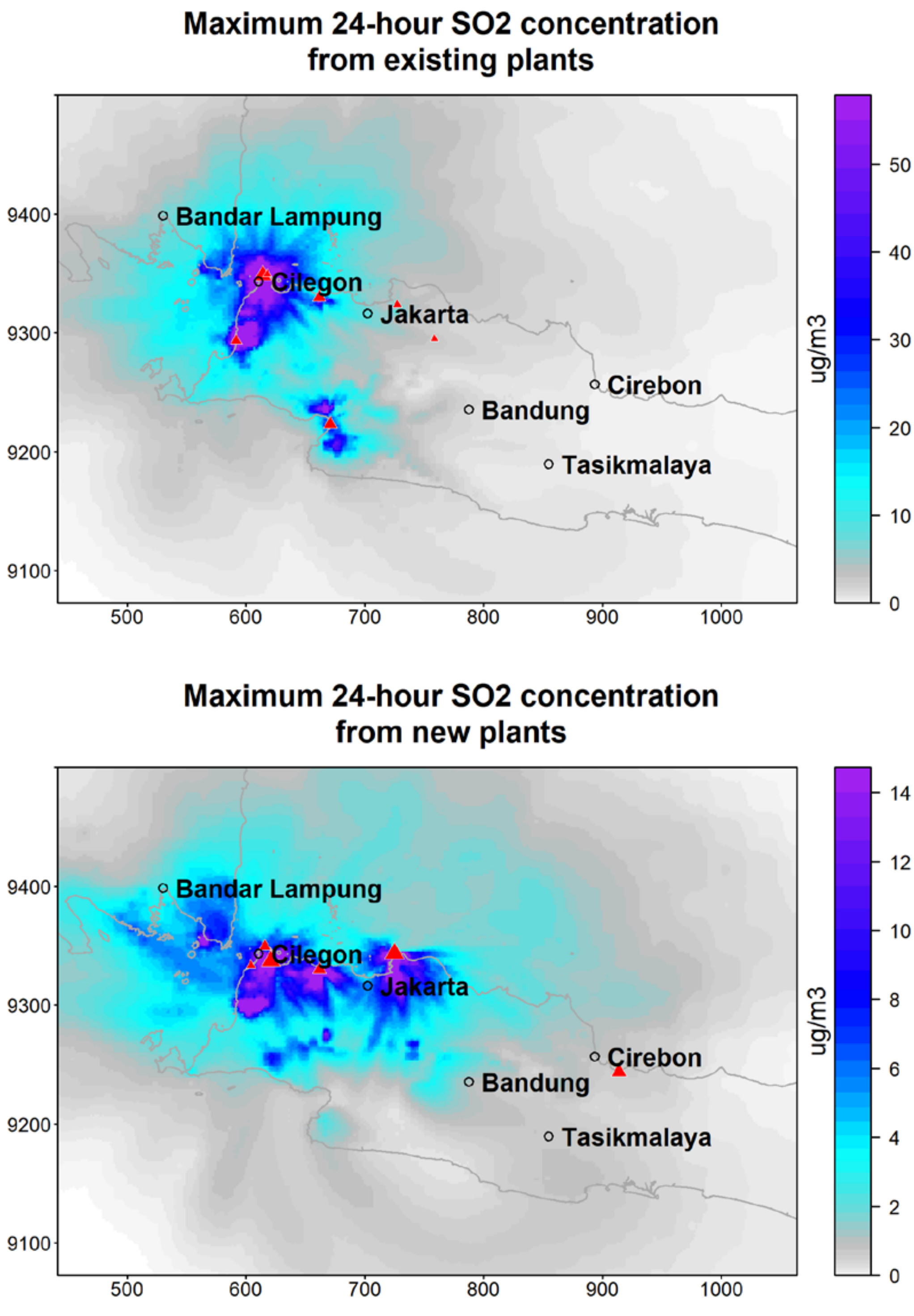


Figure 6 Projected 24-hour maximum SO_2 concentrations caused by emissions from the existing power plants (top) and new power plants (bottom).

The results shown here are based on emissions from the existing plants and future projected emissions if the planned new units are built and operated. These units would introduce a major new source of air pollution in the region. Emissions from the existing plants affect $PM_{2.5}$ pollution levels most notably around Bandar Lampung, Cilegon, as well as Tangerang and north Jakarta (Figure 2 and Figure 3 top panels). More so, about 3 million people are exposed to air pollutants concentrations which exceed the WHO guideline of 20µg/m^3 coming from the existing coal-fired power plants alone. The construction of the planned power plants would increase the daily maximum concentration of $PM_{2.5}$ by up to 20µg/m^3 around the already heavily affected areas, and create a new hotspot east of Jakarta, affecting Bekasi and east Jakarta in particular (Figure 2 and Figure 3 bottom panels). The number of people exposed to 24-hour $PM_{2.5}$ levels exceeding WHO guidelines due to coal power emissions alone would increase to around 31 million (Table 3).

A significant impact of the existing plants and new plants on the annual mean level of NO_2 is seen in the North and west regions (Figure 4 top and bottom) from Jakarta, with maximum 1-hour concentration levels NO_2 at the most affected locations exceeding the WHO guideline (200µg/m^3) in areas with a population of 3 million people, and 24-hour SO_2 levels exceeding WHO guideline (20µg/m^3) in areas with 4 million people (Figure 5 and Figure 6 top panels). Emissions from the planned coal-fired power plants would increase the maximum 1-hour levels of NO_2 and 24-hour levels of SO_2 by more than 90µg/m^3 and more than 10µg/m^3 respectively (Figure 5 and Figure 6 bottom panels), exposing an additional 2 million people to levels exceeding WHO guidelines (Table 3). In addition, emissions from the existing and new plants are likely to affect pollution levels most significantly in cities and towns to the north and west of the power plant. Out of major population centers, the highest estimated daily SO_2, $PM_{2.5}$ and NO_2 levels are in Cilegon, Tangerang, Bogor, Jakarta, Tambun and Bekasi for the existing plants (Figure 7). The construction of the new plant will increase pollutants levels not just in the areas mentioned above but also in Bandar Lampung, Bekasi, Depok, Cirebon and Palembang as well (Figure 8).

Table 3 Number of people projected to be exposed to pollution above standards or guideline levels due to emissions from studied coal-fired power plants.

Pollutant	**Period**	**Threshold**	**Source**	**People exposed to pollution above critical threshold (million)**	
				From existing plants	*From existing and new plants*
SO_2	1 hour	211.5ug/m^3	U.S. EPA	2.2	6.3
SO_2	24 hours	20ug/m^3	WHO	4.3	6.3
NO_2	1 hour	200ug/m^3	WHO	3.1	3.9
$PM_{2.5}$	24 hours	20ug/m3	WHO	2.8	30.7
mercury	yearly total deposition	125mg/ha/yr	potential risk level identified in literature	1.4	4.3

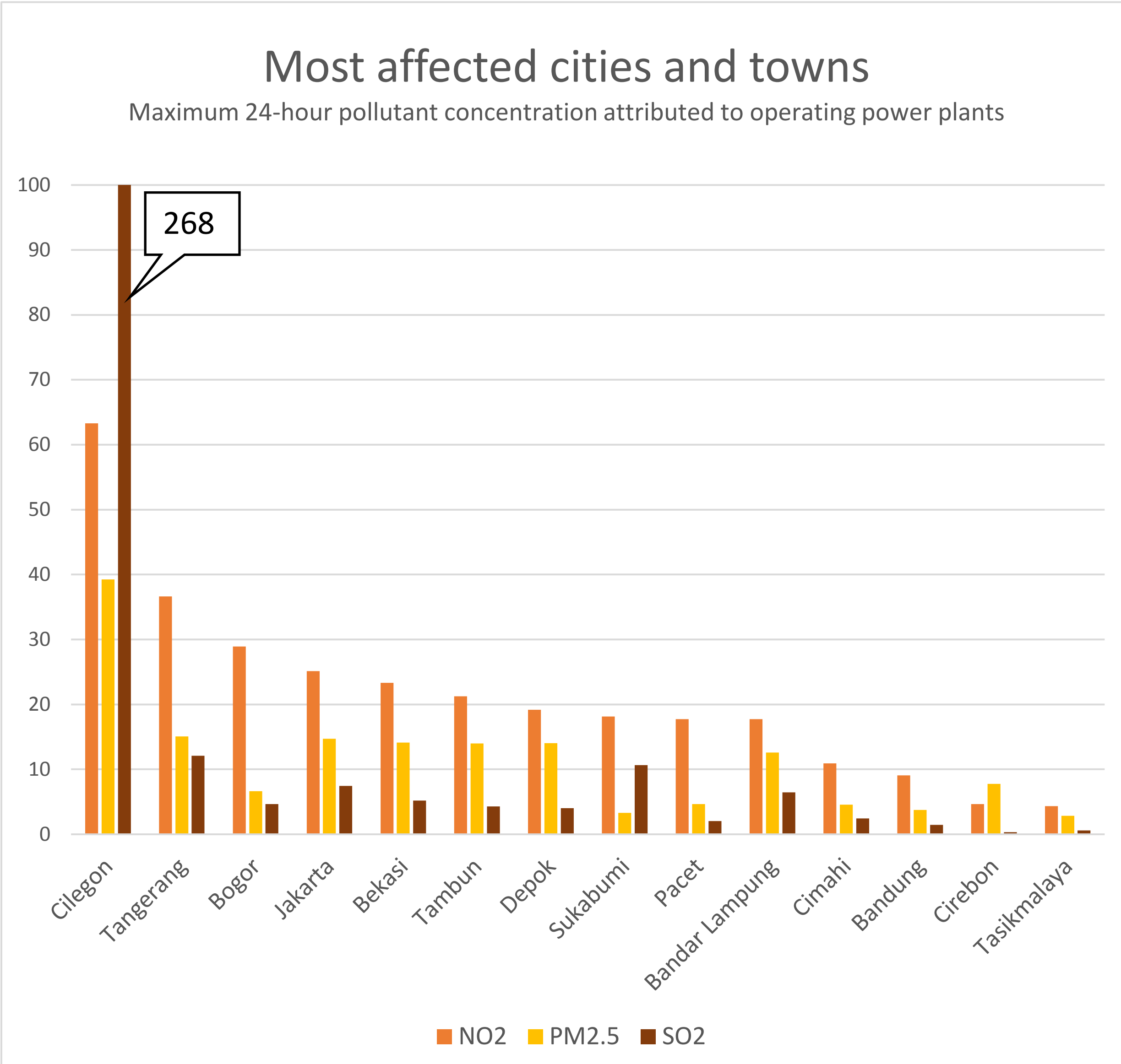


Figure 7 most affected cities and towns for the operating plants.

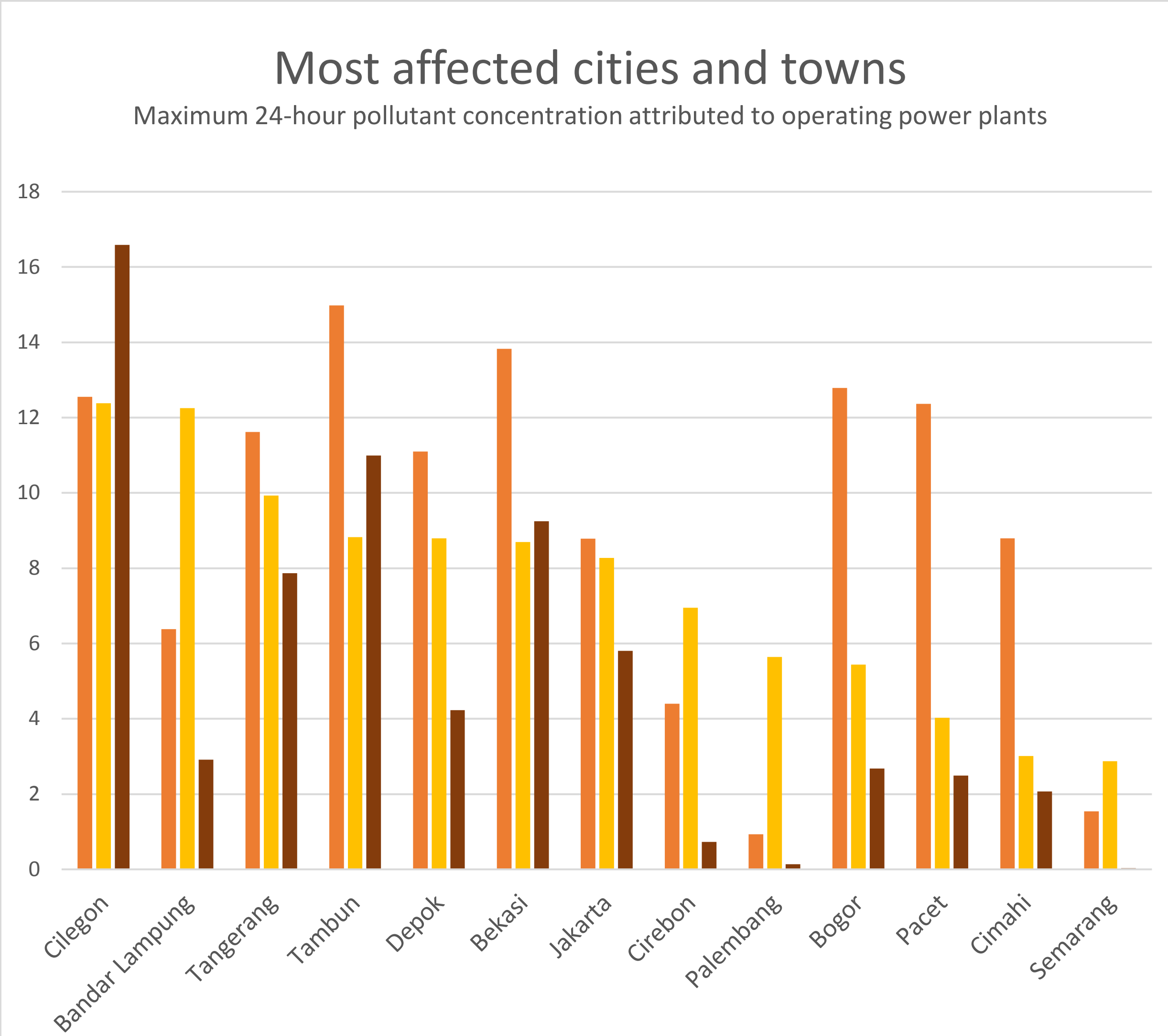


Figure 8 most affected cities and towns for the new plants.

Toxic fallout

The pollution emissions from coal-fired power plants lead to deposition of fly ash, acid rain and mercury (Figure 9 , Figure 10 and Figure 11). The deposition mainly occurs during rains. Fly ash from coal combustion contains most of the heavy metals, such as arsenic, lead, cadmium and chromium, contained in the coal. Presently, acid deposition of an estimated 40 kg of SO_2 equivalent per hectare per year and fly ash deposition of 4 kg/ha/yr takes place around Bandar Lampung and Cilegon due to emissions from operating power plants (Figure 9 top panel). The construction of the new power planned would increase acid deposition and fly ash deposition not just around Bandar Lampung but also in Jakarta and beyond (Figure 9 bottom panel). Most intense acid deposition would take place in the areas to the North West and South West of Jakarta, with most affected areas receiving above 30 kg of SO_2-

equivalent per hectare per year (Figure 9 bottom panel). The planned new power plants are likely to increase the total acid deposition in the hotspots. Acid deposition could affect agricultural yields or increase input costs for farmers who have to neutralize the deposition. Acid rain also damages property and culturally important buildings.

Also, total mercury deposition on land from the existing plant exceeds 100mg/ha/yr in the most affected areas, and 30mg/ha/yr in North West of Jakarta (Figure 11 top panel). The construction of the new plants will increase total mercury deposition by up to 100mg/ha/yr per year around Bandar Lampung, Jakarta and Bandung. The mercury emission and deposition estimates are highly uncertain as specific data on mercury content in coal or mercury emissions for the studied power plants was not available, so actual emissions and deposition could be considerably higher or lower.

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 number of people living in areas where mercury deposition from coal power plants alone exceeds this level is estimated at 1.4 million currently, and would be projected to increase to 4.3 million if new coal power plants are built and operated (Table 3).

The predicted deposition from the existing and new plants exceed this rate in the most affected regions highlighted above. 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.

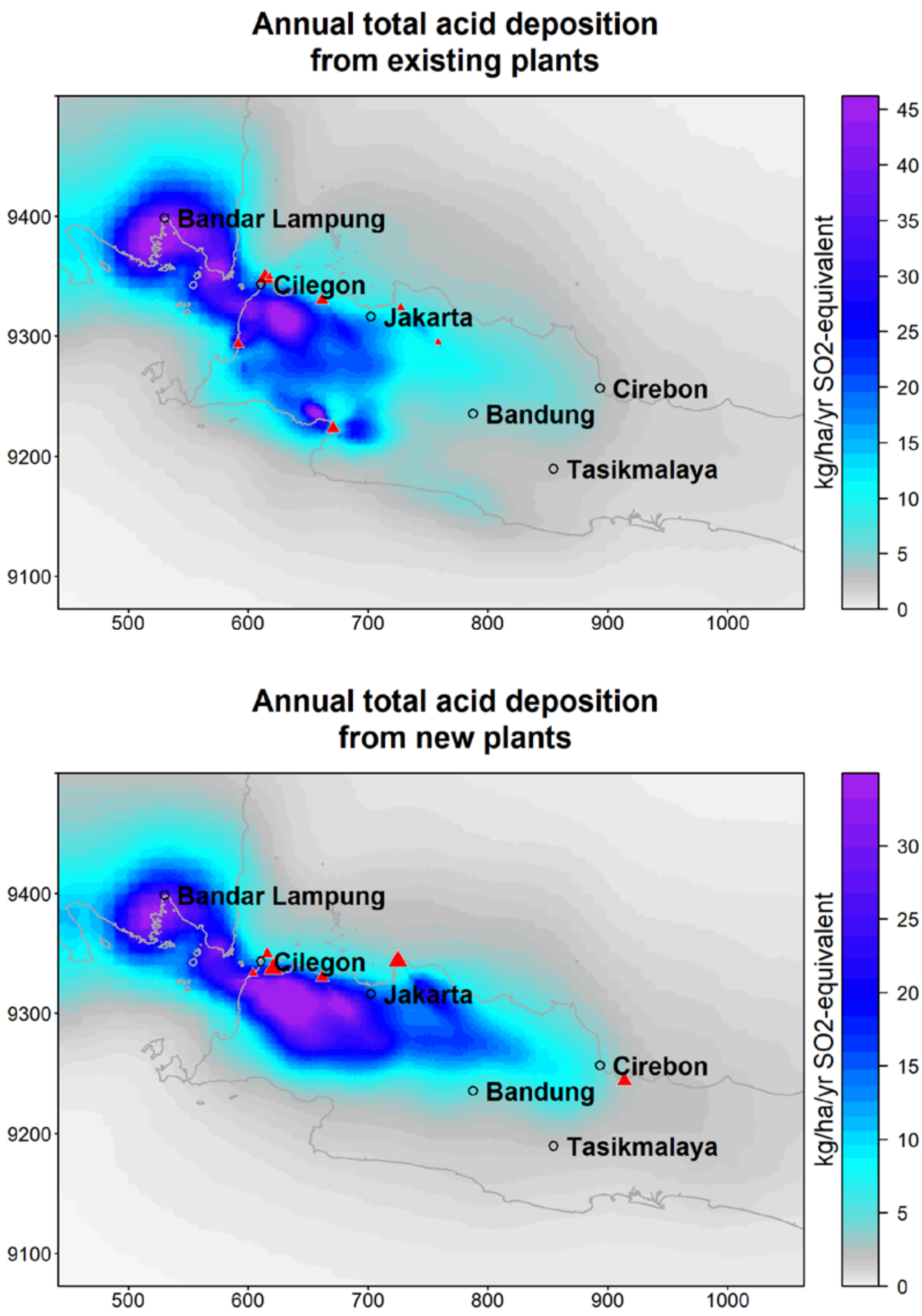
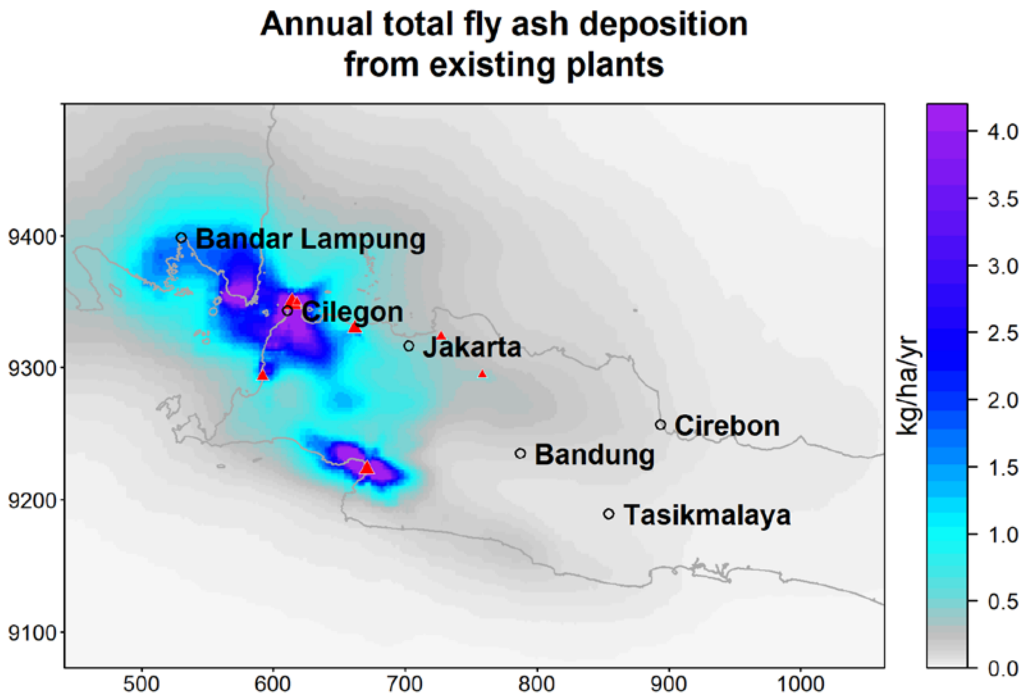


Figure 9 Projected acid deposition (SO_2 equivalent) from the existing power plants (top) and new power plants (bottom).



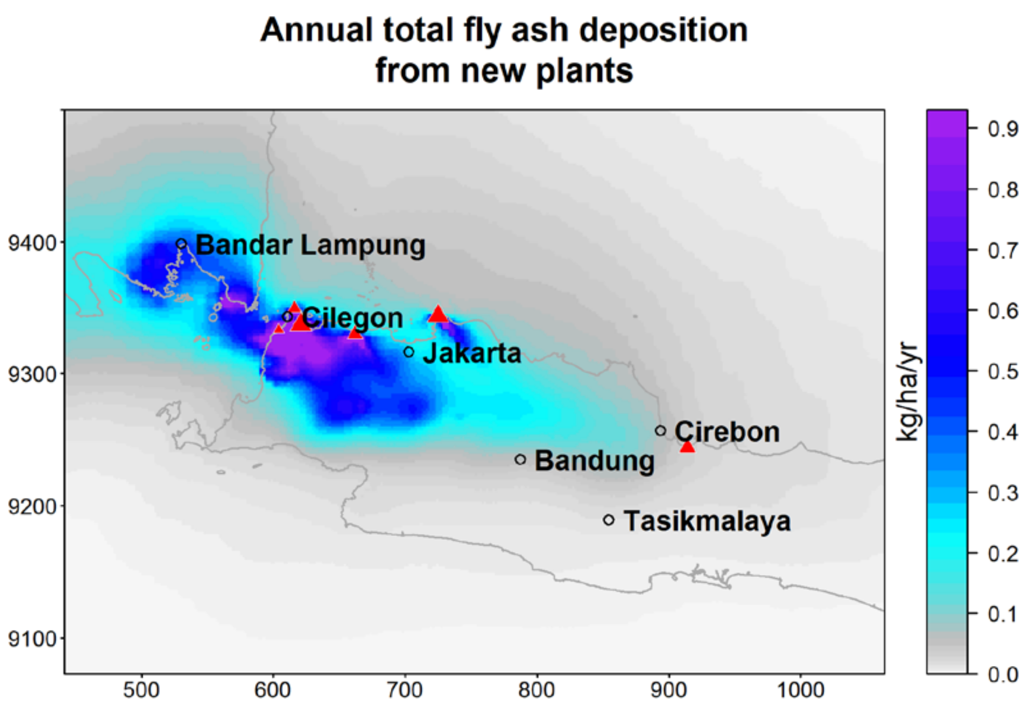


Figure 10 Projected fly ash deposition from the existing power plants (top) and new power plants (bottom).

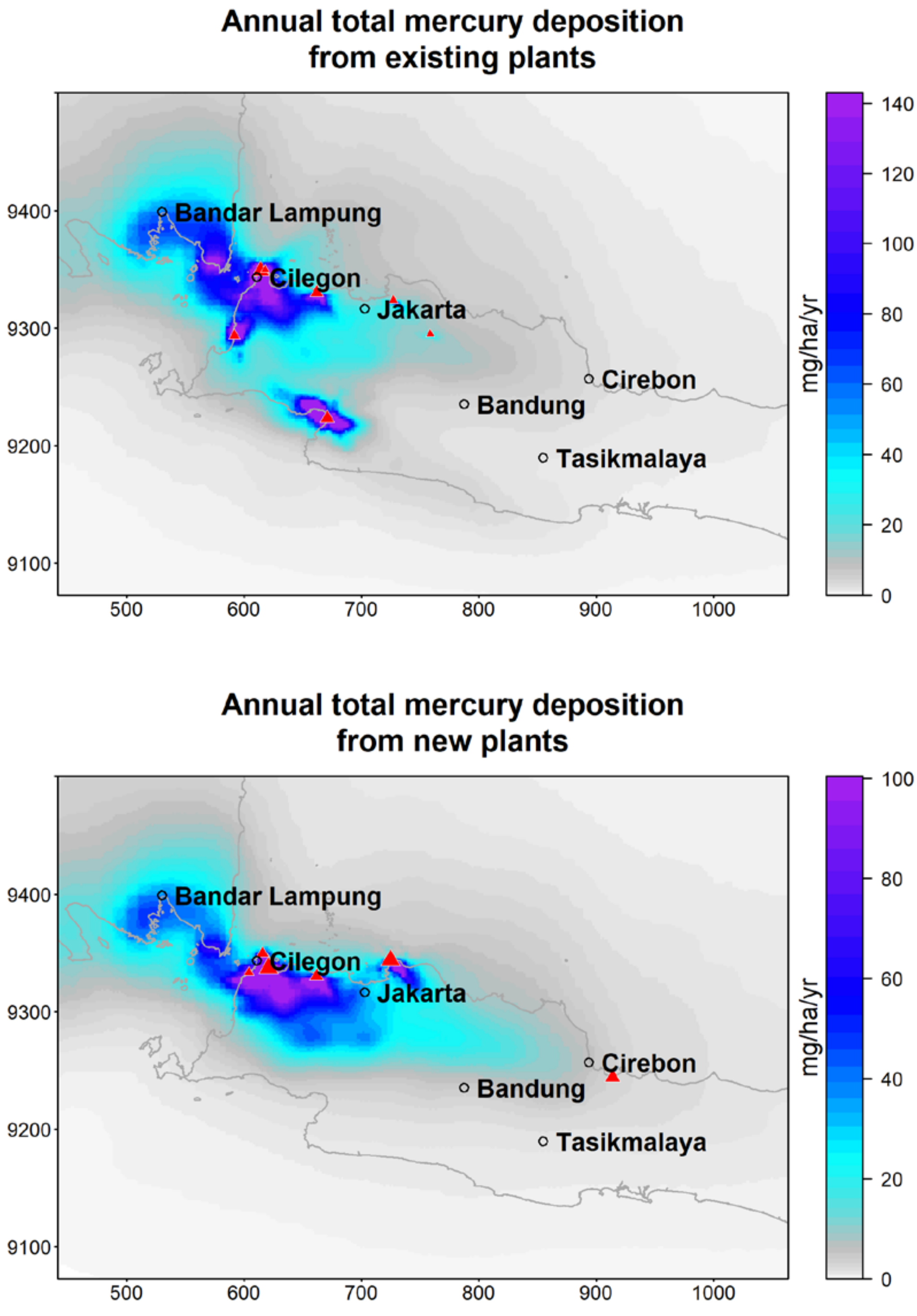


Figure 11 Projected mercury deposition from the existing power plants (top) and new power plants (bottom).

Health impacts

The emissions from the currently operating coal-fired power plants are likely to result in estimated 5,260 premature deaths and 1,690 low birth weight per year due to exposure to $PM_{2.5}$ and NO_2 (Table 4). If the proposed new coal-fired units are built and operated, they can be expected to operate for decades. It's therefore important to take into account the future population growth and changes in population age structure and health status. The health impacts were projected to 2030 assuming no change in emissions but projected increase in population and change in rates of death from different causes, which reflect factors such as improved health care and aging population. The construction of the planned coal-fired power plants would result in a projected 5420 additional deaths and 1130 low birth weight births per year.

Table 4 Projected premature deaths and other health impacts caused by emissions from the studied power plants, cases per year.

	Health effects	Operating	95% CI	New	95% CI
$PM_{2.5}$, premature deaths	Lower Respiratory Infections (infants)	90	*(20-220)*	50	*(10-110)*
	Lung cancer	130	*(60-210)*	210	*(90-340)*
	Other cardiovascular diseases	390	*(240-540)*	400	*(250-560)*
	Ischemic heart disease	1,110	*(720-1510)*	1,110	*(710-1500)*
	Stroke	1,270	*(780-1760)*	1,350	*(830-1870)*
	Other respiratory disease	140	*(90-200)*	160	*(100-230)*
	Chronic obstructive pulmonary disease	190	*(110-260)*	210	*(130-290)*
	$PM_{2.5}$ Total	3,330	*(2020-4690)*	3,490	*(2120-4890)*
NO_2, premature deaths	All causes	1,940	*(1120-4140)*	1,930	*(1110-4130)*
Premature deaths	**Total**	5,260	*(2770-7450)*	5,420	*(2870-7640)*
$PM_{2.5}$	Low birth weight births	1,690	*(520-2940)*	1,130	*(350-1960)*

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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.

Meteorological data for the simulations comes from two sources: 21 hourly surface meteorological observation stations for which data was available through U.S. NCDC under the World Meteorological Organization agreement on sharing meteorological data, and three-dimensional meteorology generated in the TAPM modeling system, developed by Australia's national science agency CSIRO. 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 30km, 10km and 5km horizontal resolutions and 12 vertical levels was used, centered on the power plant.

To 30% of emitted fly ash was assumed to be $PM_{2.5}$, and 37.5% PM_{10}, in line with the U.S. EPA AP-42 default value for electrostatic precipitators. Particles larger than 10 microns were modeled with a mean aerodynamic diameter of 15 microns. Reported annual emissions were converted into average emission rates, which were then applied throughout the year.

Chemical transformation of sulphur and nitrogen species was modeled using the ISORROPIA II chemistry module within CALPUFF, and required atmospheric chemistry parameters (monthly average ozone, ammonia and H_2O_2 levels) for the modeling domain were imported into the model from baseline simulations using the Geos-Chem global atmospheric model with nested grid for Asia (Koplitz et al., 2017).

The CALPUFF results were reprocessed using the POSTUTIL utility to repartition different nitrogen species (NO, NO_2, NO_3 and HNO_3) based on background ammonia concentrations.

The health impacts resulting from the increase in $PM_{2.5}$ concentrations were evaluated by assessing the resulting population exposure, based on high-resolution gridded population data for 2010 from NASA

SEDAC[4], and then applying the health impact assessment methodology of the Harvard-Greenpeace coal-health study. In addition, premature deaths from NO_2 exposure were assessed based on WHO (2013), increase in low birth weight births based on Dadwand et al (2013), and increase in number of children suffering from asthma based on Kan et al (2005) (see tables below). Baseline death rates in Indonesia from different causes were obtained from WHO Global Health Estimates (2014), birth rates and incidence of low birth weight from World Bank (undated), and asthma prevalence from the Global Asthma Report (GAN 2014).

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

Risk ratio for 10µg/m³ increase in $PM_{2.5}$ 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
Low birth weight	1.100	1.030	1.180	Dadwand et al 2013
Asthma prevalence	1.0695			Kan et al 2005

Risk ratio for 10µg/m³ increase in NO_2 exposure	Central	95% CI, low	95% CI, high	Reference
All causes[5]	1.037	1.021	1.08	WHO 2013

[4] http://sedac.ciesin.columbia.edu/data/set/gpw-v3-population-count-future-estimates

[5] *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).*