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Health Impacts of Units 9·10 of the Jawa Coal-fired Power Plant in Banten, Indonesia

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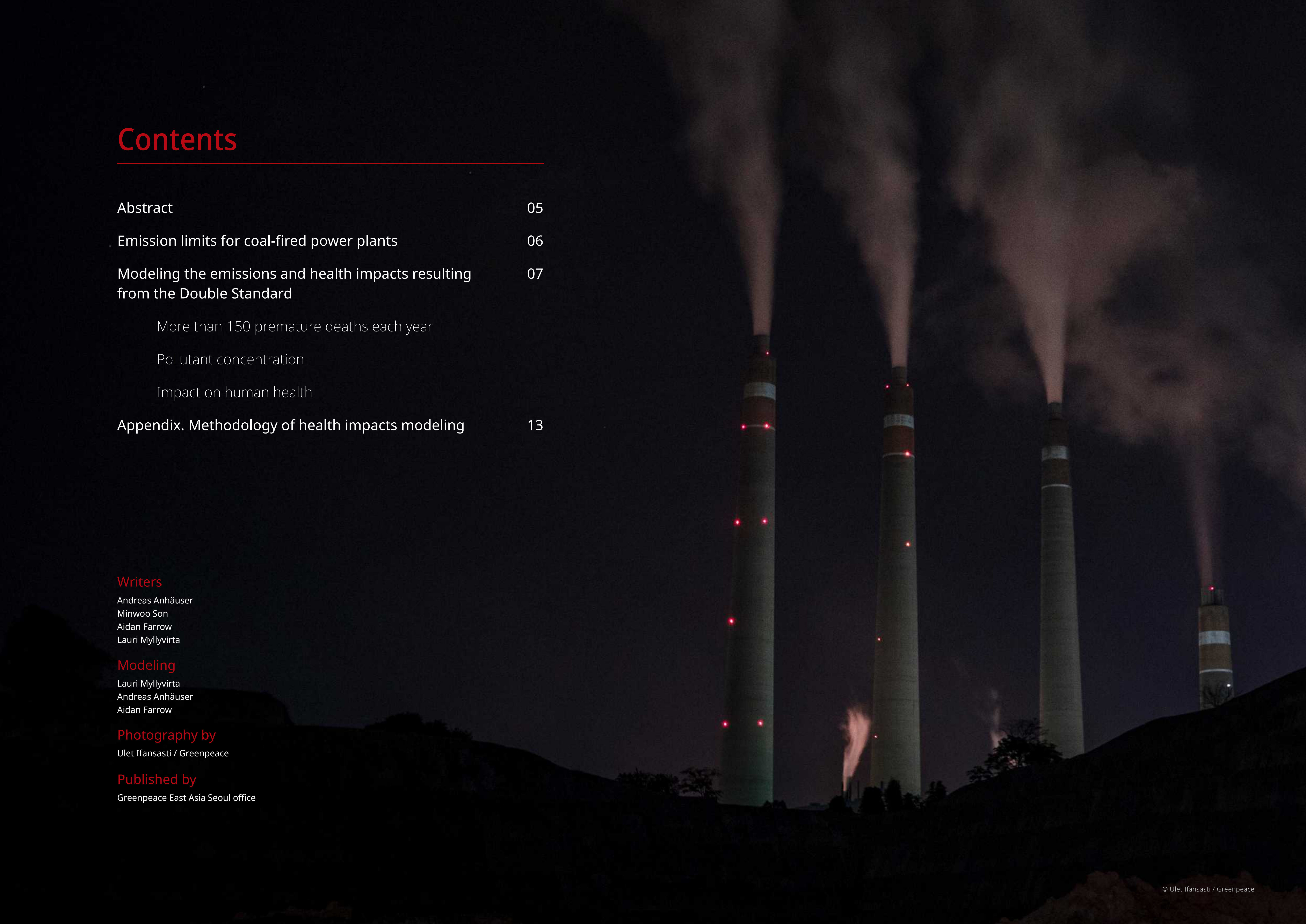

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Abstract

We present an analysis of the direct impact on human health of air pollution from units 9 and 10 of the South Korean sponsored Suralaya thermal power plant in Banten, Indonesia, better known as the Jawa thermal power plant, which is expected to be in operation from 2024. We use an atmospheric/chemistry model system to project the dispersion of the air pollutants NO_x, SO_2 and $PM_{2.5}$ emitted by the power plant to its environment for two scenarios: one where the actual local (Indonesian) emission limits are applied and one with the much stricter South Korean emission standards. We apply a widely used method to quantify the impact on the public health of the local population for each scenario and find that pollutant emissions of the two studied future units will cause between 80 and 244 additional annual premature deaths in the Indonesian population, accumulating to 2,400 to 7,300 additional premature deaths over a typical 30-year lifetime of coal-fired power plants. While 79% of these deaths would be avoided by applying the stricter South Korean emission standards, the two units' emission would still cost 500 to 1,500 lives over their 30-year lifetime.

Emission limits for coal-fired power plants

South Korean domestic emission standards for coal-fired power plants (CFPPs) in the *Clean Air Conservation Act*[1] is one of the strictest in the world, due to very strong public demands on clean air quality which is triggered by public concerns on air pollution in South Korea. Additionally, emission limits are often made stricter still at new power plants which are under construction and in operation by the demands of the government or local governments.
For example, the new 1,000-MW(2) coal fired power plant, Gangneung ECO power which is currently under construction has emissions limits of 19, 39, and 3 mg/Nm^3 for NO_x, and SO_2 and dust, respectively(3) , while the average emission limits for coal power units over 100 MW capacity that have been installed in South Korea since 2015, are 28 mg/Nm^3 for NO_x, 65 mg/Nm^3 for SO_2 and 5 mg/Nm^3 for dust, according to the respective projects' environmental impact assessments (EIAs), see Table 1 and Figure 1.[4,5]

	emission limits (mg/Nm^3)		
	NO_x	SO_2	dust
Emission standards of new CFPPs (≥ 100 MW) since January 2015 in South Korea	28	65	5
Gangneung ECO power (South Korea)	19	39	3
Jawa power station units 9·10 (Indonesia)	251	221	100

Table 1. Emission limits for CFPPs in South Korea and Indonesia. [6]

In contrast, overseas CFPP projects which are supported by South Korean public financial agencies (PFAs) apply far more lenient emission regulations on air pollution than those within South Korean borders (Table 1 and Figure 1). We present here an analysis of the environmental impact of units 9·10 of the Suralaya thermal power plant (TPP) in Banten, Indonesia, better known as Jawa thermal power plant (in the following Jawa TPP 9·10) which is currently under planning and expected to be in operation from 2024.[9] The plant will be sponsored by *Export-Import Bank of South Korea (KEXIM)* and *Korea Trade Insurance Corporation (K-SURE)*, two South Korean PFAs, with an estimated amount of 1.67 billion USD.[10] *Korea Development Bank (KDB)* also showed its intention to invest in the plant if the financing from the two PFAs is premised.[11]

When in operation, Jawa TPP 9·10 will apply emission limits that are more than 19 times more lenient than South Korean norms, namely 251, 221 and 100 mg/Nm^3 for NO_x, SO_2 and dust, respectively (Figure 1).

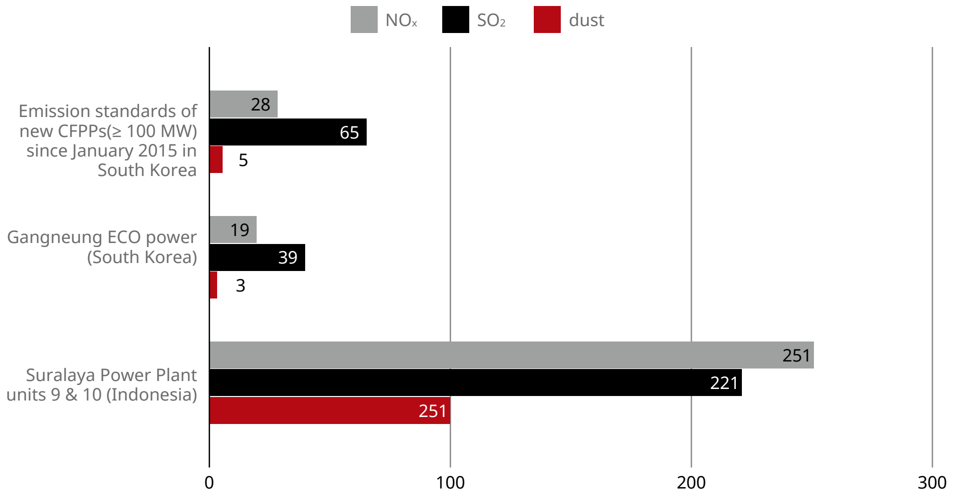

Figure 1.
Emission limits for NO_x, SO_2 and dust: South Korean emission standards since January 2015 vs. Indonesia (mg/Nm^3).[7,8]


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Modeling emissions and health impacts resulting from the double standard

In order to quantitatively assess the impacts of South Korea's double standard policy on air quality, and resulting health impacts in the Indonesian population, we modeled the dispersion of air pollutants emitted by Jawa TPP 9·10.

To allow us to quantify the impact of Jawa TPP 9·10 and the potential reduction should South Korean emission standards be followed, the model was run for two different scenarios:

- **Scenario 1:**
  Actual emissions
- **Scenario 2:**
  Applying South Korean emission standards for coal
  power plants (≥ 100 MW) installed after January 2015

Each model simulation predicts pollutant concentrations resulting from Jawa TPP 9·10 emissions for the specified emission regime over the course of one calendar year. Input data describing the emissions are extracted from the Jawa TPP EIA.[12] A detailed technical description of the model is provided in the Appendix.

More than 4,700 premature deaths in 30 years of operation

We find that emissions from Jawa TPP 9·10 will cause between 80 and 244 additional premature deaths in the Indonesian population each year, with a central (i. e. most likely) estimate of 157 cases (Table 2, Figure 2). This adds up to an expected 2,400 to 7,300 premature deaths (central estimate 4,700) over an estimated 30 years lifespan of the power generation units. These numbers do not take into account future population growth which would lead to exposure of pollutants to a higher number of people and therefore higher death counts. The numbers shown here are therefore a conservative estimate.
If the double standard in emission limits was removed and Jawa TPP 9·10 operated at South Korean emission limit values instead, between 62 and 195 annual premature deaths are likely to be avoided each year, totalling 1,900 to 5,800 saved lives over 30 years of operation (Figure 3).

	Scenario 1 (Indonesian standards)			Scenario 2 (South Korean standards)			Difference		
	central estimate	low estimate	high estimate	central estimate	low estimate	high estimate	central estimate	low estimate	high estimate
per year	157	80	244	33	18	49	124	62	195
over 30 years	4,707	2,391	7,317	984	525	1,479	3,723	1,866	5,838

Table 2. Modeled number of annual premature deaths due to excess pollution for Scenario 1 and Scenario 2, (*low* and *high* show the bounds of the 95% confidence intervals).

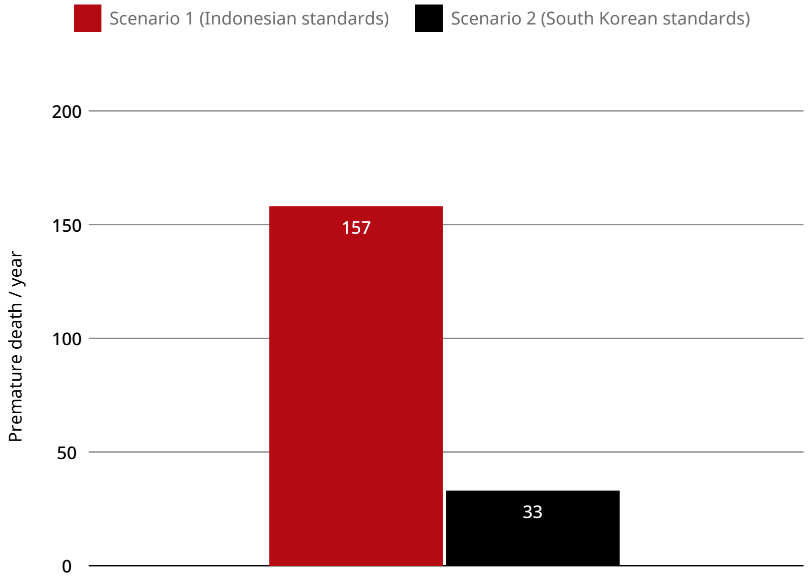

Figure 2.
Modeled number of annual premature deaths due to Jawa TPP 9·10 emission for Scenario 1 and Scenario 2. Shown are central estimates. Uncertainties are about 50% (exact values in Table 2).

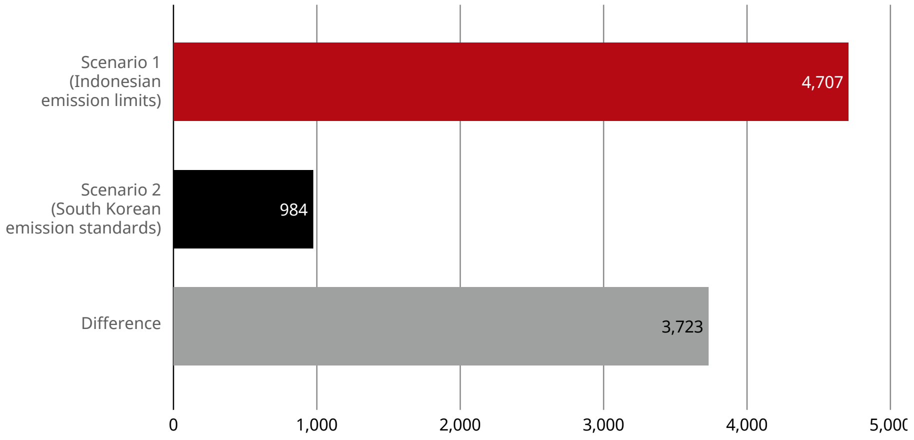

Figure 3.
Central estimates of the total premature deaths for 30 years lifespan due to Jawa TPP 9·10 emissions under Scenario 1 (Indonesian standards) and Scenario 2 (South Korean standards). The difference represents the premature deaths that can be prevented if South Korean emission standards are applied. Uncertainties are about 50% (exact values in Table 2).

Pollutant concentration

Figures 4-6 compare the projected NO_2, SO_2 and $PM_{2.5}$ pollution from Jawa TPP 9·10 between both scenarios. Pollution from the power plant spreads tens to hundreds of kilometers across and beyond the provinces of Banten, Lampung and West Java and thereby affects many densely populated regions, including the multi-million inhabitant metropolitan areas of Jakarta, Bandar Lampung and Bandung. During unfavorable meteorological conditions, or when plant emissions are worst, much higher than average pollutant concentrations are attained for short time periods (compare top to bottom rows in Figs. 4 and 6, note the different color scale). In Bandar Lampung, the highest 24-hour average concentration of $PM_{2.5}$ from Jawa TPP 9·10 is about 20 times higher than the annual average (Figure 6, bottom vs. top row).

If South Korean emission standards were applied (Scenario 2), pollutant concentrations would be reduced substantially (right column in Figs. 4-6 and bottom row in Tab. 3):

- by a factor of 9 for NO_2
- by a factor of 3 for SO_2
- by a factor of 6 for $PM_{2.5}$

	NO_2 (µg/m³)			SO_2 (µg/m³)			$PM_{2.5}$ (µg/m³)		
	annual	24h	1h	annual	24h	1h	annual	24h	1h
Scenario 1 (Indonesian standards)	0.8	16.3	241	1.3	27.9	328	0.4	8.0	73.7
Scenario 2 (South Korean standards)	0.1	1.8	27	0.4	8.2	97	0.1	1.9	13.0

Table 3. Maximum predicted concentrations at locations surrounding Jawa (Suralaya) TPP 9·10 over different averaging intervals.

Our model only includes emissions of pollutants from Jawa TPP 9·10 It does not take into account background pollution from other sources or even emissions from the other units operating at Jawa TPP. It is therefore not possible to determine all of the locations where exceedances of relevant air quality standards might occur as a result of emissions from Jawa TPP 9·10.

Emissions from Jawa TPP 9·10 elevate the levels of particulate matter and gaseous pollutants in the air over a large area spanning hundreds of kilometers. In many areas the increased pollution burden from Jawa TPP 9·10 is projected to be small. These small increments however cannot be considered in isolation. Emissions from Jawa TPP 9·10 add to pollution from other sources. When they combine the contribution to pollution from Jawa TPP 9·10 could cause or increase the chances of an exceedance of air quality guidelines in any location with an pre-existing air quality problem.

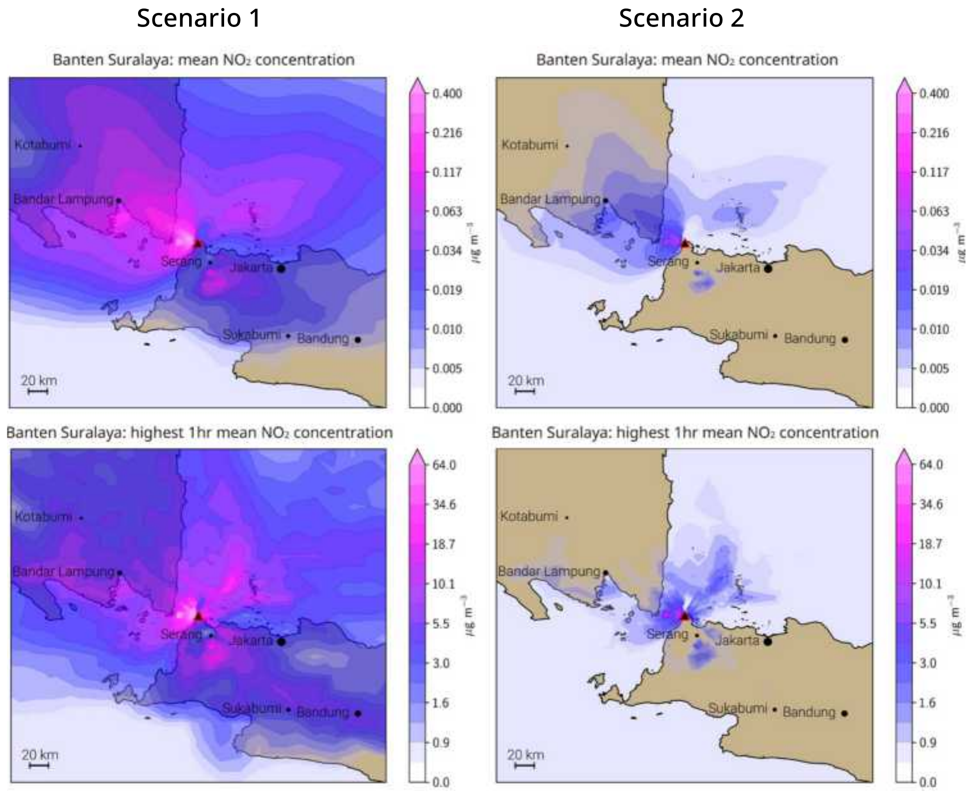

Figure 4.
Modeled future additional NO_2 concentration due to emissions from Jawa (Suralaya) TPP 9·10 (triangle). Top row: annual mean, bottom row: maximum 1-hour mean. Left column: Scenario 1, right column: Scenario 2. Note that the color scales are logarithmic and different between rows.

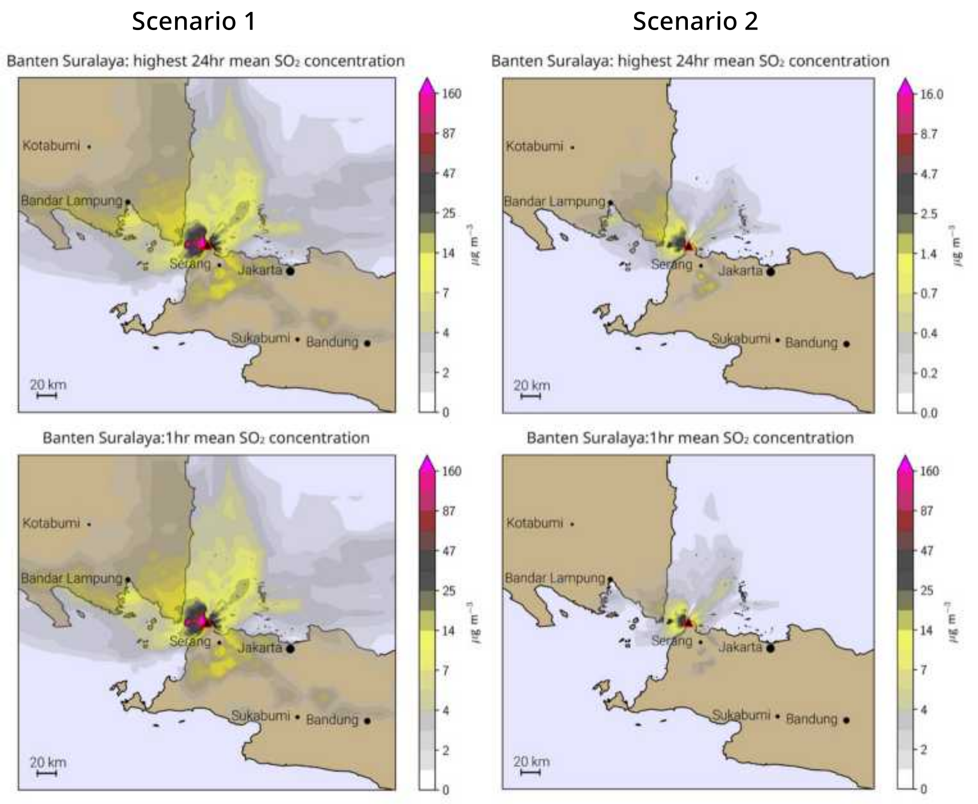

Figure 5.

Modeled future additional SO_2 concentration due to emissions from Jawa (Suralaya) TPP 9·10 (triangle). Top row: maximum 24-hour mean, bottom row: maximum 1-hour mean. Left column: Scenario 1, right column: Scenario 2. Note that the color scales are logarithmic and different between rows.

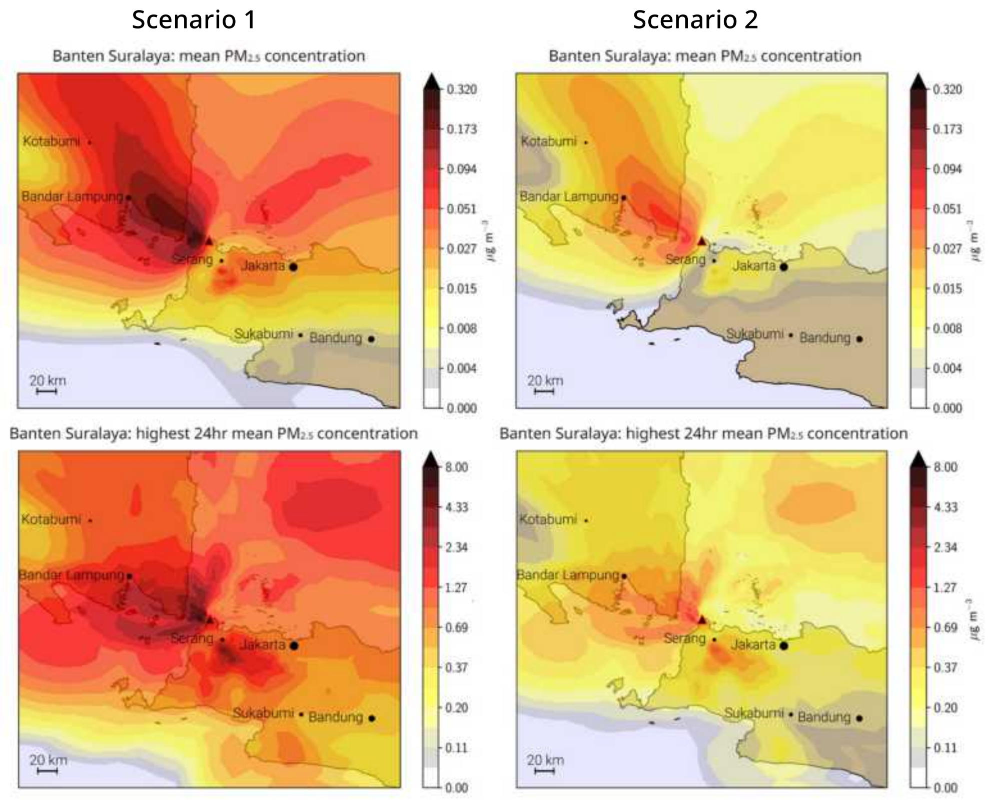

Figure 6.

Modeled future additional $PM_{2.5}$ concentration due to emissions from Jawa (Suralaya) TPP 9&10 (triangle). Top row: annual mean, bottom row: maximum 24-hour mean. Left column: Scenario 1, right column: Scenario 2. Note that the color scales are logarithmic and different between rows.

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Impact on human health

Exposure to air pollution carries a substantial risk of respiratory and cardiovascular diseases, cancer and other diseases, especially for vulnerable groups such as children, elderly people, and people with pre-existing respiratory ailments. Applying a widely used health impact assessment method[13,14,15] (see Appendix), we modeled the number of additional annual premature deaths due to pollution from Jawa TPP 9·10 emissions for both scenarios.

The results are shown in Table 4. In Scenario 1, the emissions from Jawa TPP 9·10 are projected to cause between 80 and 244 premature deaths each year, adding up to a total of 2,400 to 7,300 premature deaths over an expected 30-year lifespan of the power plant.[16] More than two thirds of these fatalities are due to diseases caused by $PM_{2.5}$ pollution, most importantly ischemic heart disease (34% of all casualties).

The death toll could be reduced by 79% to 17-49 annual premature deaths if South Korean emission standards were applied, which would save 62 to 195 lives each year and a total of 1,900 to 5,800 over the average 30-year lifetime of the power plants (Table 4).

		Scenario 1 (project emissions limits)			Scenario 2 (South Korean standards)			Difference		
Pollutant	Cause	central estimate	low estimate	high estimate	central estimate	low estimate	high estimate	central estimate	low estimate	high estimate
$PM_{2.5}$	COPD	7	4	10	2	1	3	6	3	8
	Lung cancer	5	2	7	1	0	2	3	1	5
	LRI	5	0	9	1	0	2	3	0	7
	Diabetes	7	1	13	2	0	3	5	1	10
	IHD	54	35	74	14	9	18	41	26	55
	Stroke	34	21	47	8	5	12	26	16	35
	Total	**111**	**62**	**160**	**28**	**15**	**40**	**84**	**47**	**120**
NO_2	**All causes**	**46**	**17**	**84**	**5**	**2**	**9**	**41**	**16**	**74**
Total (annual)		**157**	**80**	**244**	**33**	**17**	**49**	**124**	**62**	**195**
Total (30 years)		**4,710**	**2,388**	**7,320**	**981**	**522**	**1,479**	**3,726**	**1,866**	**5,838**

Table 4. Modeled number of annual premature deaths by cause.

Appendix. Methodology of Health Impacts Modeling

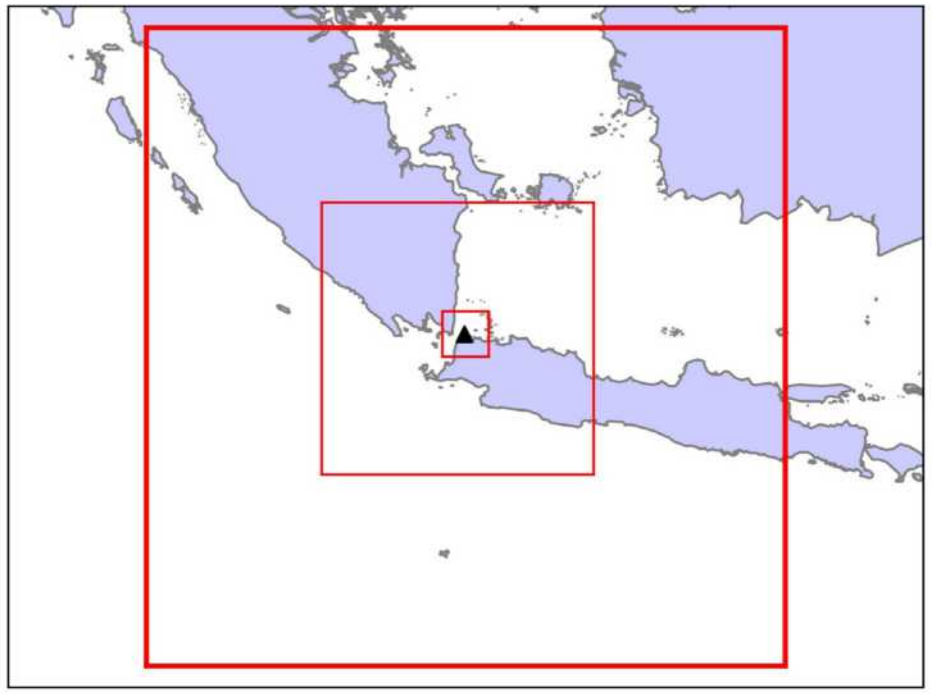

Figure A.1:
The numerical weather model is run in three nested domains (red boxes) around the source (black triangle).

Method overview

The impacts of the emissions from the power station is derived using a combined approach that uses an atmospheric dispersion modelling system to estimate pollutant concentrations and demographic data to estimate health effects.

1. Atmospheric dispersion modeling system

The atmospheric dispersion model consists of two major components. A meteorology module is used to simulate the regional meteorological conditions around the power plant. This is combined with a chemistry-transport model to study the propagation of the power plant emissions to its environment.

a) Meteorology model. The meteorology around the power plant is modeled using version 3 of the *The Air Pollution Model (TAPM)*.[17] Although TAPM includes the ability to model pollutant dispersion, only the meteorology component of TAPM is used. It is run on three nested domains centred around the CFPP. The model domains have 37x37 grid cells with spatial resolutions of 40 km, 10 km and 2.5 km, respectively, getting finer towards the center (Figure A.1). Boundary conditions are derived from the GASP model of the Australian Bureau of Meteorology[18]. In each TAPM simulation, the model has a nine day spin up period covering the last nine days of 2017. TAPM is then run for the whole year of 2018, to provide data for the analysis.

b) Atmospheric chemistry-transport model. The dispersion, chemical transformation and deposition of the power plant emissions of NO_x, SO_2 and primary $PM_{2.5}$ is modeled by version 7 of the CALPUFF model[19]. As we are solely focusing on the impacts from the power plant, no other emission sources are included in the model. Background concentrations of O_3, NH_3 and H_2O_2 are included for use by the chemistry module[20]. Both emission scenarios (Scenario 1, actual emission limits vs. Scenario 2, South Korean emission standards) are modeled. The model outputs a time series of near-surface concentrations of the pollutants for analysis at gridded receptor locations across the model domains.

c) Emission data sources. The pollutant emission rates and flue gas release characteristics used for the modeling are based, as far as possible, on data disclosed by the project proponents. The following data was collected from the project's environmental impact assessment:

- ○ Pollutant concentrations in flue gas (CFG)
- ○ Plant electric capacity (CAP)
- ○ Steam condition (subcritical/supercritical/ultra-supercritical)
- ○ Coal type
- ○ Flue gas release temperature and velocity
- ○ Stack location

The plant's net thermal efficiency (EFF) is assumed at 44%, a typical value for ultra-supercritical plants. The stack height and inner stack diameter are extracted from the EIA document of Jawa TPP 9·10 project.[21]
To assess both short-term maximum air quality impact and annual pollutant exposure and health impact, data on both the annual emission volume (AEV) and emission rates at full operation (ER) is required. The AEV was calculated from

$$\mathrm{ER} = \mathrm{AEV} / \mathrm{PLF}$$

where PLF is the projected plant load factor, effectively assuming that the CFG is constant throughout plant operation, a conservative assumption with respect to projected maximum short term air quality impact. As both ER and AEV were unavailable, the ER was calculated as

$$\mathrm{ER} = \mathrm{FGV} * \mathrm{CFG}$$

with FGV being the flue gas volume flow. As the FGV was unavailable, it was estimated as:

$$\mathrm{FGV} = \mathrm{CAP} / \mathrm{EFF} * \mathrm{SFGV}$$

where SFGV is the specific flue gas volume per unit thermal input (Nm^3/GJ) estimated for the type of coal used by the power plant.
To estimate the SFGV values based on net calorific value, moisture and ash content of coal, the empirical formula A.5N on p. 85 of European standard EN 12952-15 was used. Coal characteristics were obtained from averages for Sumatran coal, commonly used in power plants on Java, in the USGS World Coal Quality Inventory.[22]

Once AEV and ER were obtained, the atmospheric model was run for a full calendar year at the full-operation emissions rates, and the resulting ground-level pollutant concentration fields were used as such for assessing maximum short-term air quality impact. For the purposes of health impact assessment, the average concentrations were scaled down by PLF, effectively spreading the plant's annual emissions volume evenly through the year.

2. Health impact assessment

The results of the pollution model (step 1) are used to assess the number of people exposed to concentrations that violate the WHO guidelines and to estimate the impact of this pollution on the health of the local human population.

a) Exposure to guideline level exceedances. Using global population data with 1 km resolution, we assessed the number of people living in areas that exceed WHO guidelines. There are guidelines that refer to annual average concentration and others that refer to average concentrations within a shorter time interval. For those referring to annual average concentrations, we used the temporal mean of the full year of analysis time. For the shorter time interval concentrations, we calculated for each of the chemical model receptors individually the maximum value of the appropriate temporal running mean.

b) Health impact. The number of fatalities caused by the excess pollution have been assessed using empirical values of relative risks relating various causes of premature deaths to increases in pollutant concentrations. The relative risk r expresses how much more likely an individual is to die prematurely if they are exposed to a certain excess pollution than if they were not exposed:

$$m_x / m_0 = r \quad (1)$$

where m_x is the mortality (number of deaths per number of inhabitants) under the increased pollution Δx, and m_0 is the mortality in absence of the excess pollution. In state-of-the-art epidemiological models, r depends exponentially on x for $m_x \ll 1$:[23,24]

$$r = \exp(c\,\Delta x) \quad (2)$$

with c being a constant called concentration response factor. Combining Eqs. (1) and (2) gives

$$m_x = m_0 \exp(c\,\Delta x)$$

Since the number of deaths is the population number P times the mortality, the number of people dying under the higher pollutant concentration is

$$d_x = P\, m_0 \exp(c\,\Delta x).$$

The number of deaths attributable to the excess pollution is

$$\Delta d = d_x - d_0 = P\, m_0 [\exp(c\,\Delta x) - 1]$$

Values for r in the scientific literature may be broken down to different death causes or be a total for one substance.

Data sources for the health impact assessment

- **Population.** We used the 1km resolution global population data for 2010 from Socioeconomic Data and Applications Center (SEDAC).[25]
- **Country boundaries** are taken as defined in version 3.6 (May 2018) of the GADM project.[26]
- **Concentration response factors (CRFs).** We used the CRFs listed in Tab. A.1. CRFs have been computed from relative risks given in WHO (2013)[27] for NO_2, Pope et al. (2015)[28] for $PM_{2.5}$-*diabetes*, Mehta et al. (2011)[29] for $PM_{2.5}$-*lower respiratory infections* and Krewski et al. (2009)[30] for all other $PM_{2.5}$. The same values are used for all age groups.[31]
  - Elimination of double-counting effects: Up to 33% of the NO_2-caused deaths may overlap with cases due to $PM_{2.5}$ exposure.[32] To account for possible double counting when summing up death numbers from different causes, we modified the raw numbers NO2-caused deaths after applying the CRFs:
    - we reduced the lower bound of by 33%
    - we reduced the central estimate by 16.5%
    - we kept the upper bound unchanged (as the authors give no lower limit of the overlap).

    All numbers for NO_2 deaths that are shown in this report have already been corrected in this way.
- **Background mortality** is taken from the IHME Global Burden of Disease Study 2017.[33] The data set provides national average values per cause of death. The numbers used in this report are listed in Tab. A.2.

Allocation of death cause names from the CRFs to background death rates is shown in Tab. A.3.

	NO_2		$PM_{2.5}$[34]	
	relative risk at 10 µg m^{-3} increase	CRF (10^{-3}µg^{-1} m^3)	relative risk at 10 µg m^{-3} increase	CRF (10^{-3} µg^{-1} m^3)
All causes [35,36]	1.055 (1.031-1.080)	5.354 (3.053-7.696)	-	-
Lower respiratory infections	-	-	1.128 (1.077-1.182)	11.33 (2.96-26.24)
Lung cancer	-	-	1.142 (1.057-1.234)	13.28 (5.54-21.03)
Chronic obstructive pulmonary diseases	-	-	1.128 (1.077-1.182)	11.33 (2.96-26.24)
Diabetes	-	-	1.128 (1.077-1.182)	11.33 (2.96-26.24)
Stroke	-	-	1.128 (1.077-1.182)	11.33 (2.96-26.24)
Ischemic heart disease	-	-	1.287 (1.177-1.407)	25.23 (16.30-34.15)

Table A.1. Concentration response factors for NO_2 and $PM_{2.5}$ derived from relative risks for a standard increase of 10 µg/m^3. The CRFs have been computed from the relative risks using Eq. (2). Brackets show 95% confidence intervals. For NO_2, there is no data on specific death causes (thus, only the aggregated health impact of all causes is assessed for this pollutant).

	All	LRI	LC	COPD	Diabetes	Stroke
Indonesia	5652 (5198-6138)	245 (209-294)	161 (139-186)	412 (366-468)	159 (134-187)	1030 (933-1138)

Table A.2. Background death rates used in this report from the 2017 IHME Global Burden of Disease dataset. Annual deaths per million with 95% confidence ranges. Death causes are abbreviated as in Table A.3.

CRF	Background death rate
All causes (all)	All causes
Lower respiratory	Lower respiratory infections
Lung cancer (LC)	Tracheal, bronchus, and lung cancer
Chronic obstructive pulmonary disease (COPD)	Chronic obstructive pulmonary disease
Diabetes	Diabetes mellitus type 2
Stroke	Stroke
Ischemic heart disease (IHD)	Ischemic heart disease

Table A.3. Correspondence between death cause names in the CRF sources and in the background death rate data (highlighting where the causes don't match precisely).

Footnote

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31. The CRFs found by Krewski et al. apply to people aged 30 years and older. In the present report, we worked on the assumption that the same CRFs also apply to people below 30.
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34. Values for *ischemic heart disease* and *chronic obstructive pulmonary diseases* were listed with wrong values in a previous report on the same subject (Double standard: How Japan's financing of highly polluting overseas coal plants endangers public health, Greenpeace Southeast Asia, August 20, 2019). However, in the actual calculations for health impact assessment, the correct values were used.
35. Up to 33% of these cases may overlap with cases due to $PM_{2.5}$ exposure.
36. In a previous report on the same subject, erroneously 1.021 was used instead of 1.031 for the lower bound of the relative risk. This lead to a slight underestimation of the lower bound of the death number.

Health Impacts
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