



# Air quality impacts of the Banten-Suralaya complex

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## CREA

Centre for Research on Energy and Clean Air

CREA is an independent research organisation focused on revealing the trends, causes, and health impacts, as well as the solutions to air pollution.

## **Air quality impacts of the Banten-Suralaya complex**

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# Air quality impacts of the Banten-Suralaya complex

## Key findings

- Using the mean value from measurements (Base scenario), this study finds that the Banten-Suralaya complex located on the Indonesian island of Java in the Banten province leads to high levels of air pollution over a large and densely populated region, including annual-mean  $\text{PM}_{2.5}$  concentrations of  $1.0 \mu\text{g m}^{-3}$  over the northern half of the Banten province, which has a population of 13 million people and includes Serang and Cilegon.
- The air pollution from the Banten-Suralaya complex has a devastating impact on public health and the economy, including the annual loss of 1,470 lives and health damages that cost USD 1.04 billion (IDR 14.2 trillion).
- Using the maximum value from measurements (Base\_Max scenario), this study finds that the impacts of the Banten-Suralaya complex increase further still, reaching annual deaths of 1,640 and health damages that cost USD 1.16 billion (IDR 15.8 trillion).
- In the maximum value scenario (Base\_Max scenario), the 1,640 deaths include 1,063 deaths caused by exposure to  $\text{PM}_{2.5}$  leading to deaths among the adult population due to stroke (401), ischaemic heart disease (365), lower respiratory infections (91), chronic obstructive pulmonary disease (86), lung cancer (72), and diabetes (16), as well as in children under the age of 5, due to lower respiratory infections (8).
- This study finds that, if the Banten-Suralaya complex achieves compliance with national standards (Compliance scenario), then the air pollution, human health, and economic impacts from this facility decrease.
- This study finds that enforcing compliance will lead to annual savings of 97 human lives when compared to the scenario using the mean value from measurements (Base scenario), and 268 human lives when compared to the scenario using the maximum value from measurements (Base\_Max scenario)



- In addition to saving lives, achieving full compliance also leads to annual savings of 141–300 emergency room visits, 17–236 new asthma cases in children, 74–157 preterm births, 48–103 underweight births, and 59,000–125,000 work absences (Table A2).
- Air quality impacts reduce even further if air pollution control measures are installed (best available technology, BAT, scenario).
- With the best available technologies (BAT) for air pollution installed in the Banten-Suralaya complex, this power station complex leads to annual mean  $\text{PM}_{2.5}$  concentrations of less than  $0.2 \mu\text{g m}^{-3}$ , the annual loss of 113 human lives, and annual damages of USD 50 million (IDR 700 billion).
- Compared to the scenario using the mean value from measurements (Base scenario), this corresponds to a 90 % reduction in air pollution mortality and economic burden, which equates to an annual saving of 1,357 lives and USD 960 million (IDR 13.1 trillion).
- Compared to the scenario using maximum value from measurements (Base\_Max scenario), this corresponds to an annual saving of 1,527 lives and USD 1.08 billion (IDR 14.7 trillion).
- In addition to saving lives, implementing best available technology (BAT) would also lead to annual savings of 1,642–1,792 emergency room visits, 932–1,164 new asthma cases in children, 853–942 preterm births, 561–615 underweight births, and 680,000–746,000 work absences (Table A2).
- Enforcing compliance with national standards and implementing best available technology (BAT) for air pollution control measures have the potential to save thousands of lives and millions of dollars each year.
- Furthermore, continuous, transparent, and publicly available monitoring data would greatly improve decision-making by the government and Banten-Suralaya power station.
- The only way to entirely eliminate the air quality burden of the Banten-Suralaya complex is by replacing it with renewable sources of energy.

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## Introduction

Indonesia has undergone rapid development in recent years, leading it to become the largest economy in Southeast Asia and the fourth most populated country in the world (The World Bank, 2022a). However, poor air quality severely impacts both the health and the economy of the country. Coal combustion is a significant contributor to Indonesian air pollution due to the large size of the fleet, where individual facilities are allowed to operate in close proximity to big cities while breaching the government's lenient standards for emissions, and without using all available emission control measures or publishing continuous monitoring data of pollutant emissions.

## Background

Combustion of any fuel leads to the formation of a wide range of pollutants in the atmosphere, including fine particles ( $\text{PM}_{2.5}$ ), nitrogen dioxide ( $\text{NO}_2$ ), sulfur dioxide ( $\text{SO}_2$ ), and ozone ( $\text{O}_3$ ). Once inhaled by humans, these pollutants lead to a wide variety of diseases, ranging anywhere from chronic coughing to death. As a result of these health outcomes, air pollution leads to a loss of productive labour and increased health care expenditures.

The health impacts of  $\text{PM}_{2.5}$  have been established through decades of research. Exposure to  $\text{PM}_{2.5}$  can lead to deaths among children and adults, through diseases including ischaemic heart disease, chronic obstructive pulmonary disease, lung cancer, stroke, and diabetes (Lelieveld et al., 2019, Burnet et al., 2018). In addition to death, exposure to  $\text{PM}_{2.5}$  is also associated with a range of other health outcomes, including asthma emergency room visits (Anenberg et al., 2018), premature and underweight babies (Chawanpaiboon et al., 2018), work absences (EEA, 2014), dementia and Alzheimer's disease (Shi et al., 2020; Shi et al., 2023), depression (Xue et al., 2021), bronchitis (Kelly, 2021), and pneumonia (Zhang et al., 2021). Moreover, recent scientific research reveals that the risk of mortality due to exposure to  $\text{PM}_{2.5}$  is even higher than previous estimates (Di et al., 2017). As a result of this mounting body of scientific evidence, the World Health Organization (WHO) has halved the recommended annual guideline value from 10 to  $5 \mu\text{g m}^{-3}$  (WHO, 2021).

Indonesia suffers from severe air pollution. The Air Quality Life Index (AQLI) found that annual mean  $\text{PM}_{2.5}$  concentrations can exceed  $50 \mu\text{g m}^{-3}$  in Indonesia, breaching the WHO guideline value by a factor of 10 (AQLI, 2021). Exposure to this pollutant leads to 94,000

deaths each year in Indonesia (McDuffie et al., 2021) and reduces life expectancy by up to five years (AQLI, 2021). Overall, Indonesian air pollution-related illnesses cost over USD 220 billion each year, which is equivalent to 6 % of the country's Gross Domestic Product (GDP) (The World Bank, 2022b). In the nation's capital, Jakarta, which has a rapidly increasing air pollution public health crisis (Vohra et al., 2022), air pollution has led to 10,000 deaths and health damages costing USD 3 billion (Syuhada et al., 2023). In Cilegon, which is situated in the Banten province, daily mean  $PM_{2.5}$  concentrations can reach  $60 \mu g m^{-3}$  (Myllyvirta & Chuwah, 2017), which is four times higher than the daily value recommended by the WHO ( $15 \mu g m^{-3}$ ). While this air pollution originates from a variety of activities, a significant fraction is attributed to the country's large fleet of coal-fired power plants, of which one of the largest complexes is located in Banten province.

Energy production from coal in Indonesia has doubled in the last decade to reach 41 gigawatts (GW), making it the seventh-largest coal fleet in the world (EMBER, 2021). Indonesia has pledged to transition its economy and energy system, notably entering into the Just Energy Transition Partnership, where USD 20 billion will be used to help reach net zero by 2050 (The White House, 2022). However, the Global Energy Monitor (GEM) and Institute for Essential Services Reform (IESR) find that an additional 15 GW are under construction, and another 11 GW are in pre-construction (GEM, 2022, IESR, 2023). Under this pipeline, Indonesia will have the fourth largest coal fleet, behind China and India (GEM, 2023a). Coal-fired power plants are a remarkable source of pollution, both in Indonesia (Anhäuser, 2019; McDuffie et al., 2021; Koplitiz et al., 2017) and on a global scale (McDuffie et al., 2021).

In coal-fired power plants, the combustion of coal leads to the formation of pollutants that are emitted into the atmosphere from the stack in the "flue gas". These pollutants include both gases ( $NO_x$ ,  $SO_x$ , and gaseous mercury) and particles ( $PM_{2.5}$ ). These pollutants undergo long-range transport in the atmosphere – potentially traveling hundreds of kilometers – and therefore affect the health of both local and distant communities.

Governments can reduce air pollution from coal-fired power plants by (i) replacing coal-fired power plants with renewable energy sources, (ii) mandating the installation of air pollution control measures, (iii) setting ambitious limits on pollutant flue gas concentrations and ensuring enforcement, and (iv) enforcing the publishing of industrial emissions with transparent documentation and methodology. For instance, examples of air pollution control measures include fabric filters (baghouses) to best reduce particulates, flue gas desulphurisation (FGD) to reduce  $SO_x$ , selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR) to reduce  $NO_x$ , and activated carbon

injection (ACI) to reduce mercury emissions (International Energy Agency, 2012). Requiring coal-fired power plants to publicly report their emissions, together with transparent methodology, allows regulators and scientists to monitor the situation. However, Indonesia has a large fleet of coal-fired power plants, where many facilities are allowed to operate without sufficient air pollution control measures while breaching the government's lenient standards for pollutant flue gas concentrations, and without publicly reporting pollutant emissions.

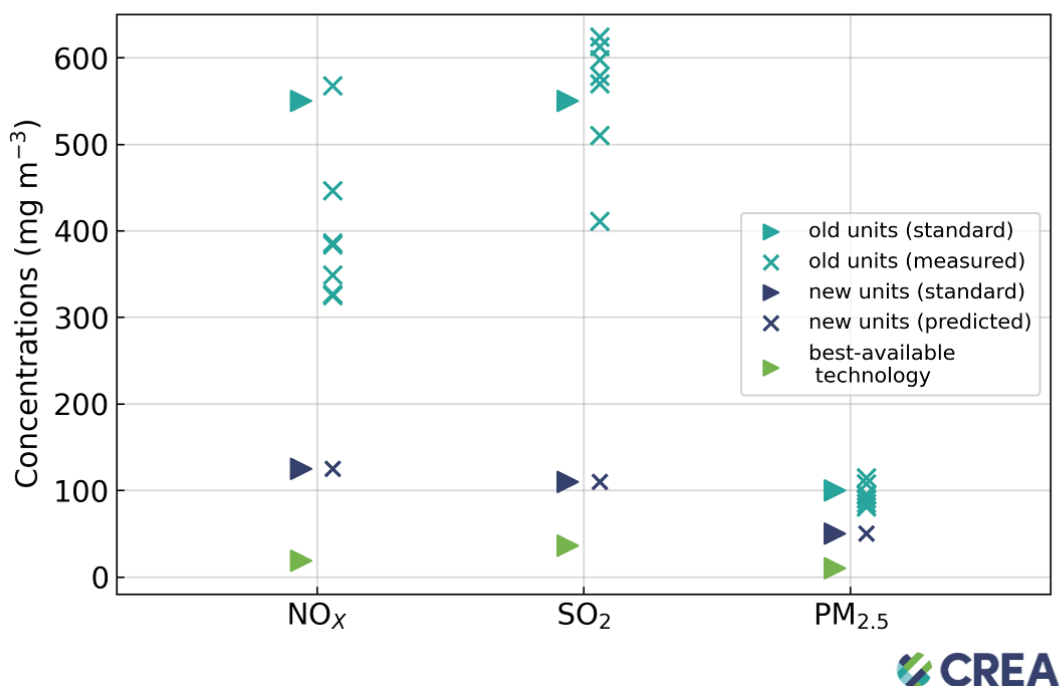
There are several examples around the world of how strengthened air quality policies, including emission mitigation measures in coal-fired power plants and public transparency, have improved air quality and public health. Over several decades (1970–2000), air quality policies and investments in emission mitigation have improved air pollution levels across Europe, which have prevented the loss of 80,000 lives and EUR 241 billion each year (Turnock et al., 2018). But air quality improvements can also be made over much shorter time frames, and also in countries that are undergoing rapid economic development and industrialisation. For example, in the space of just a few years (2014–2020), annual-mean  $PM_{2.5}$  concentrations in China have decreased by 40 % due to ambitious air quality policies, which have contributed to an increased life expectancy of up to five years (AQLI, 2022).

## **The Banten-Suralaya power station complex**

The Banten-Suralaya complex is one of Indonesia's largest coal power complexes, located on the northwest tip of Java near the cities of Serang and Cilegon, about 150 km west of Jakarta. Previous Centre for Research on Energy and Clean Air (CREA) research has shown that emissions from coal-fired power plants in Banten affect the health of communities in Jakarta (Myllyvirta et al., 2020). The power station consists of eight units built between 1984 and 2011 with a combined power capacity of 4 GW, and two units under construction to be completed between 2025 and 2026 with a combined capacity of 2 GW (GEM, 2023b). Units 1 to 4 (1.6 GW), which came online between 1984 and 1989, have exceeded their lifetime but continue to operate. The complex is owned by Perusahaan Listrik Negara (PLN), which is a national electricity company owned by the Indonesian government, and the USD 1.7 billion spent on developing the two additional units was financed by loans from private banks in South Korea: Export-Import Bank of Korea (KEXIM), the Korea Development Bank (KDB Bank), and the Korea Trade Insurance Corporation (K-sure) (Jong, 2018). Many groups strongly oppose the expansion of the complex (Betahita, 2020;

Darussalam, 2020), including the United Nations Environment Programme (UNEP) (UNEP, 2017; Anhäuser et al., 2019).

Figure 1 shows pollutant flue gas concentrations at the Banten-Suralaya complex based on measurements from UNEP for existing units and technical specifications for new units, and how they relate to Indonesian standards and best-available technology (BAT) (UNEP, 2017). Across the existing units, measurements indicate that units are mostly compliant with the national limits. However, as the measurements across existing units were recorded over a period of a few days, it is unclear whether the mean values shown here are representative of the whole year. Moreover, PLN indicates that these units encounter frequent exceedances in national limits (PLN, 2020). If maximum values from the measurements are used instead, the average pollutant flue gas concentrations of  $\text{NO}_x$ ,  $\text{SO}_2$ , and  $\text{PM}_{2.5}$  across all units increase by 22, 10, and 2 %, respectively.



Source: UNEP (2017)

**Figure 1. Pollutant flue gas concentrations (mg m<sup>-3</sup>) at the Banten-Suralaya complex**

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Note: The turquoise triangles show the Indonesian standard for existing units and the turquoise crosses show the mean measured concentrations for existing units at Banten-Suralaya (UNEP, 2017). The navy blue triangles show the Indonesian standard for new units and the navy blue crosses show the predicted concentrations for new units of Banten-Suralaya. The green triangles show the concentrations which can be achieved if the best available technology (BAT) is implemented.

Overall, Indonesian standards on flue gas concentrations for newer units are approximately twice as strict as the limit for older units. For the two new units which are currently under construction, the maximum pollutant flue gas concentrations guaranteed by the developers of the emission mitigation technology are slightly higher than the Indonesian standards for new units. Hence, these units are designed to potentially regularly exceed the legal limits for pollutant concentrations. However, the pollutant flue gas concentrations which can be achieved under the best available technology (BAT) are substantially lower (over 90 %) than the measured and assumed pollutant flue gas concentrations in the existing and proposed units.



## Results

### Scenarios investigated in this study

In this study, we evaluated air quality from all 10 units of the Banten-Suralaya complex, and how it would be affected by achieving compliance with national standards for pollutant flue gas concentrations, or by implementing the best available technology (BAT) (Table 1). In the first scenario (Base), we used pollutant flue gas concentrations that have been measured across the existing units (turquoise crosses in Figure 1) and the maximum guaranteed values across the units under construction (navy blue crosses in Figure 1). In the second scenario (Base\_Max), we used the maximum pollutant flue gas concentrations that have been measured across the existing units (turquoise crosses in Figure 1) and the maximum guaranteed values across the units under construction (navy blue crosses in Figure 1). In the third scenario (Compliance), any measured or assumed flue gas concentrations that exceed the national standard were forced to equal the national standard (turquoise and navy blue triangles in Figure 1). In the fourth scenario (BAT), pollutant flue gas concentrations across all units were forced to equal the values that can be attained by implementing best available technology (BAT) (green triangles in Figure 1). For each of these scenarios, we calculated pollutant emissions into the atmosphere, the corresponding atmospheric concentrations and deposition rates, and the health and economic impacts. For a detailed description of the methods, see Methodology section.

**Table 1. Pollutant flue gas concentrations under the different scenarios investigated in this study**

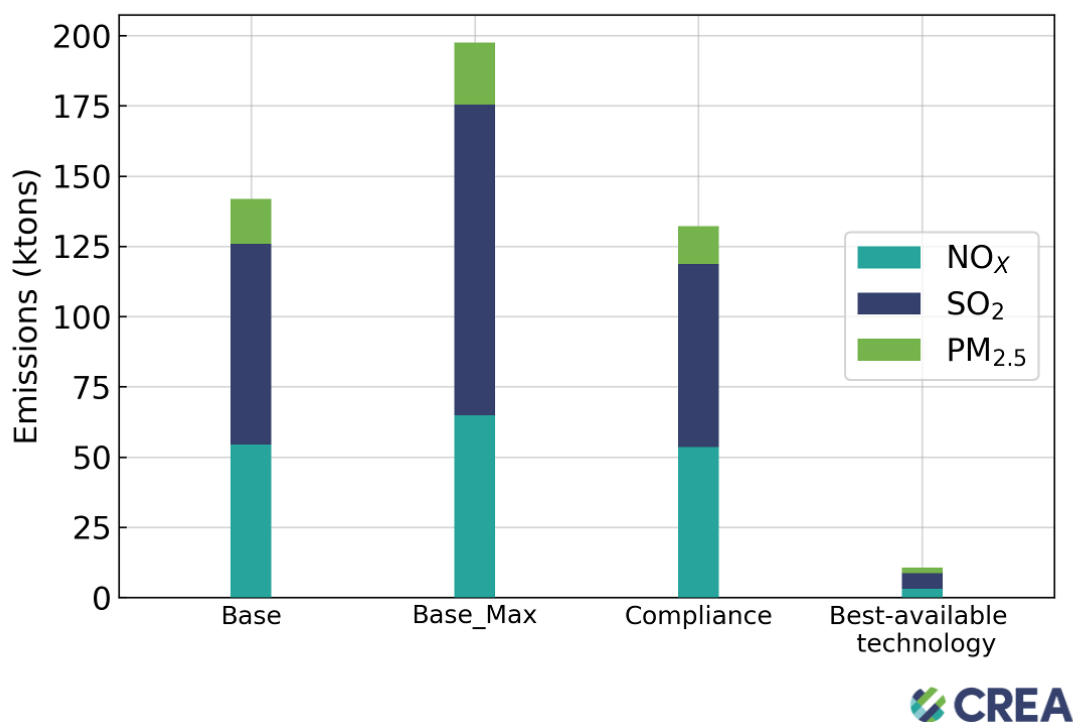
Scenario	Old Units	New Units
Base	Measured mean values, taken from UNEP (2017).	Maximum values guaranteed by designers of control efficiency, taken from UNEP (2017).
Base_Max	Measured maximum values, taken from UNEP (2017).	Maximum values guaranteed by designers of control efficiency, taken from UNEP (2017).
Compliance	Same as <i>Base</i> scenario, except for units that exceed the Indonesian standard for old units, which are forced to be compliant.	Same as <i>Base</i> scenario, except for units which exceed the Indonesian standard for new units, which are forced to be compliant.

	(NO <sub>x</sub> = 550 mg m <sup>-3</sup> ; SO <sub>2</sub> = 550 mg m <sup>-3</sup> ; PM <sub>2.5</sub> = 100 mg m <sup>-3</sup> )	(NO <sub>x</sub> = 125 mg m <sup>-3</sup> ; SO <sub>2</sub> = 110 mg m <sup>-3</sup> ; PM <sub>2.5</sub> = 50 mg m <sup>-3</sup> )
Best available technology (BAT)	<p>All units use the flue gas concentrations that can be achieved when BAT is implemented.</p> <p>(NO<sub>x</sub> = 15 mg m<sup>-3</sup>; SO<sub>2</sub> = 25 mg m<sup>-3</sup>; PM<sub>2.5</sub> = 5 mg m<sup>-3</sup>)</p>	<p>All units use the flue gas concentrations that can be achieved when BAT is implemented.</p> <p>(NO<sub>x</sub> = 15 mg m<sup>-3</sup>; SO<sub>2</sub> = 25 mg m<sup>-3</sup>; PM<sub>2.5</sub> = 5 mg m<sup>-3</sup>)</p>

Source: UNEP (2017)

## Pollutant emissions

Figure 2 shows pollutant emissions from the Banten-Suralaya complex under three different scenarios of pollutant flue gas concentrations (Table 1). Using the mean measured pollutant flue gas concentrations across the existing units and the maximum guaranteed value for new units (Base), the total annual emissions of pollutants (NO<sub>x</sub>, SO<sub>2</sub>, PM<sub>2.5</sub>) from Banten-Suralaya complex is 142 kilotonnes (kt) (Figure 2). However, there is a large range of uncertainty associated with the measured pollutant flue gas concentrations, and using the maximum values (Base\_Max), pollutant emissions increase by 39 %, to 198 kt per year (Figure 2).



Source: UNEP (2017)

**Figure 2. Annual pollutant emissions (kt per year) from the Banten-Suralaya complex**

Note: Emissions are calculated based on the flue gas concentrations shown in Figure 1 (UNEP, 2017). Each bar represents total emissions across all 10 units of the Banten-Suralaya complex under three different scenarios (Base, Compliance, and BAT) for NO<sub>2</sub> (turquoise), SO<sub>2</sub> (navy blue), and PM<sub>2.5</sub> (green).

Under full compliance with national standards for pollutant flue gas concentrations (Compliance scenario), the Banten-Suralaya complex would emit 132 kt of pollutants (Figure 2). This is equivalent to a 7 % reduction in emissions if compared to the scenario using mean measurements from UNEP (Base scenario), and a 33 % reduction if compared to the scenario using maximum measurements from UNEP (Base\_Max scenario).

With the best available technology (BAT) installed in Banten-Suralaya, the complex would emit 7 kt of pollutants each year (Figure 2). This corresponds to a reduction of over 90 % of pollutant emissions compared to the scenarios using measured pollutant flue gas

concentrations (Base and Base\_Max scenarios). The reason for this substantial decrease in emissions is that air pollution control measures can be extremely effective in mitigating pollutant emissions in coal-fired power plants.

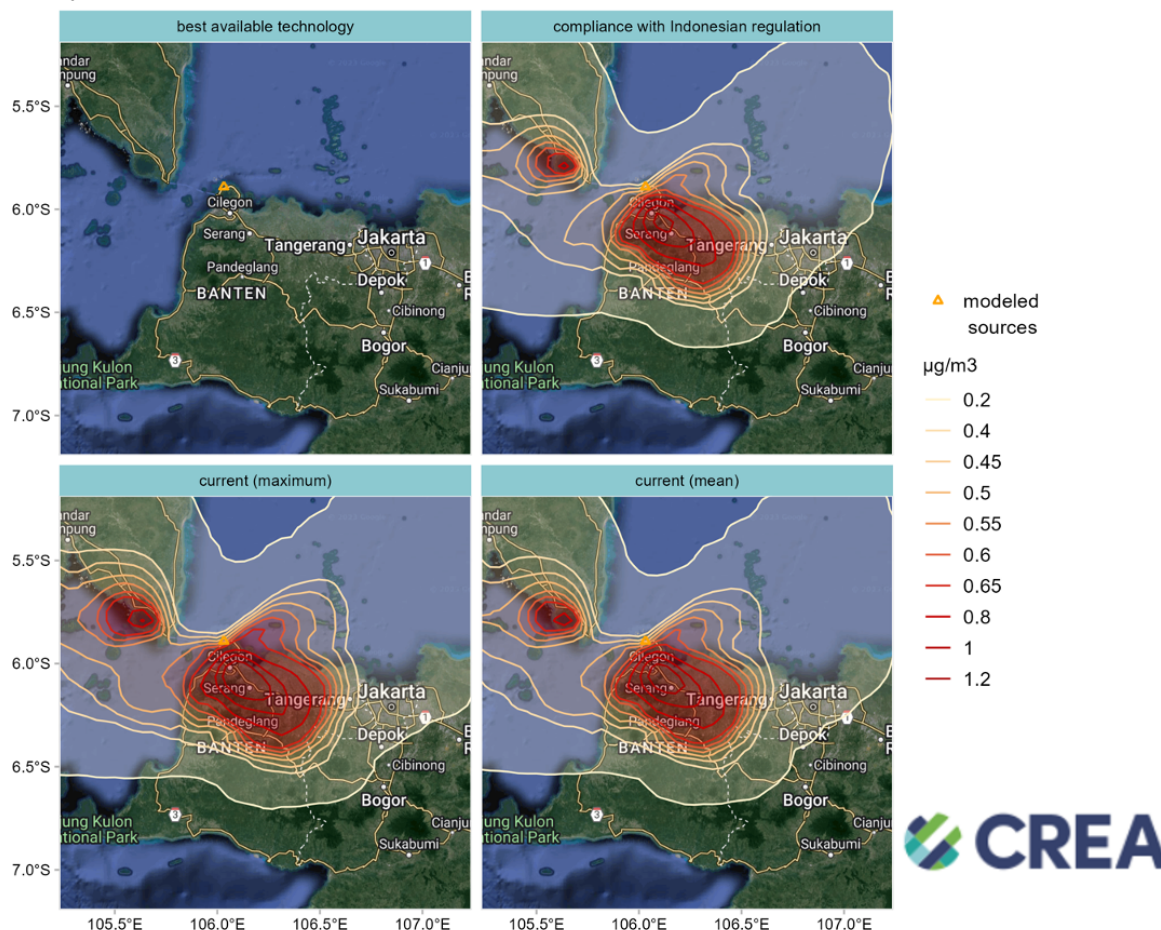
## Pollutant concentrations and deposition

For each of the different scenarios (Table 1), we used the pollutant emissions from all 10 units of the Banten-Suralaya complex (Figure 2) to simulate the corresponding atmospheric concentrations and surface deposition rates from the Banten-Suralaya complex, and the results for annual mean  $PM_{2.5}$  concentrations are shown in Figure 3. First, we present the health impacts of air pollution from Banten-Suralaya under measured pollutant flue gas concentrations across the existing units and the maximum guaranteed value for new units (Base and Base\_Max), and then we present how this will change if the plants become compliant (Compliance) or if they implement best available technology (BAT).

Using the mean measured pollutant flue gas concentrations across the existing units and the maximum guaranteed value for new units (Base), annual mean  $PM_{2.5}$  concentrations from the Banten-Suralaya complex reach  $1.0 \mu g m^{-3}$  (Figure 3). For context, there is no safe exposure level for  $PM_{2.5}$  and the WHO recommends that  $PM_{2.5}$  exposure levels do not exceed  $5 \mu g m^{-3}$  annually. The Banten-Suralaya complex not only affects  $PM_{2.5}$  concentrations in the immediate vicinity but also in surrounding areas. High simulated  $PM_{2.5}$  concentrations are sustained over the northern half of the Banten province, which has a population of 13 million people. In addition to  $PM_{2.5}$ , the Banten-Suralaya complex leads to simulated annual mean  $NO_2$  and  $SO_2$  concentrations of  $1\text{--}1.4 \mu g m^{-3}$  (Figure 5, top panel) and  $0.5\text{--}2.0 \mu g m^{-3}$  (Figure 6, top panel), respectively. Moreover, residents of western Java and southern Sumatra are not only exposed to air pollution from the Banten-Suralaya complex, but also other power plants (Anhäuser, 2019; Myllyvirta, 2020), traffic (Pun et al., 2020), and biomass burning (Reddington et al., 2014). Using the maximum measured pollutant flue gas concentrations across the existing units and the maximum guaranteed value for new units (Base\_Max), simulated  $PM_{2.5}$  concentrations are even higher (Figure 3).

### Annual mean PM<sub>2.5</sub> concentration from Banten Suralaya complex

by scenario



Source: Simulated using CALPUFF (Exponent, 2015).

**Figure 3. Annual PM<sub>2.5</sub> concentrations (µg m<sup>-3</sup>) from the Banten-Suralaya complex**

Note: Different panels represent each emission scenario investigated in this study (Base - top; Compliance - middle; BAT - bottom).

Achieving full compliance decreases simulated atmospheric concentrations of PM<sub>2.5</sub> (Figure 3), NO<sub>2</sub> (Figure A1), and SO<sub>2</sub> (Figure A2). This is due to the lower emissions associated with the compliance scenario (Figure 2).

Implementing BAT reduces atmospheric concentrations of pollutants. For instance, simulated annual mean PM<sub>2.5</sub> concentrations decrease by ~90 %, from around 1.0 in the

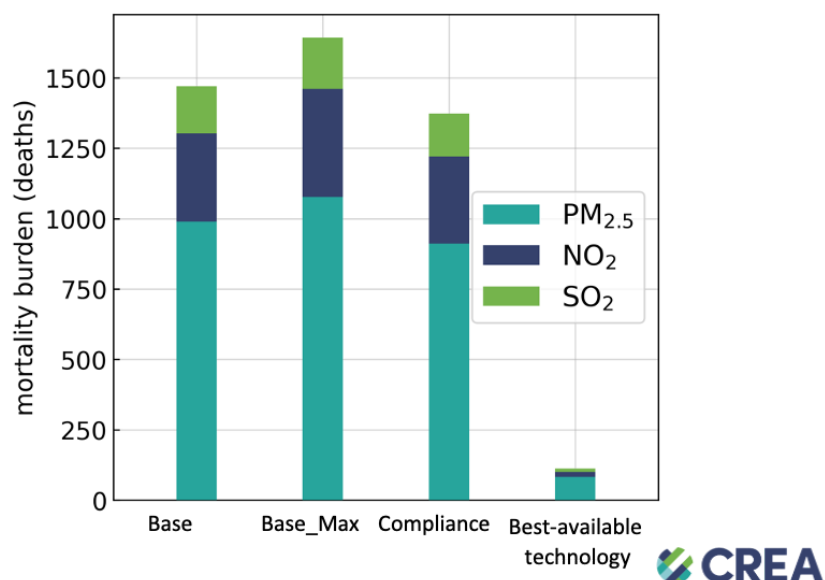
Baseline scenario to less than  $0.2 \mu\text{g m}^{-3}$  in the BAT scenario (Figure 3). Similarly,  $\text{NO}_2$  (Figure A1) and  $\text{SO}_2$  (Figure A2) also decrease significantly (~90 %) when stronger emission control technologies are implemented.

Overall, the emissions from the Banten-Suralaya complex lead to significant air pollutant concentrations over a large and highly populated region of Indonesia. But concentrations of the pollutants drop substantially when units are compliant with national standards or have BAT installed.

## Pollutant health impacts

We calculated the human health impacts of air pollution from the Banten-Suralaya complex for the scenarios shown in Table 1. Figure 4 and Table A1 show the impact of pollution from the Banten-Suralaya complex on annual mortality. First, we present the health impacts of air pollution from the Banten-Suralaya complex under measured pollutant flue gas concentrations across the existing units and the maximum guaranteed value for new units (Base and Base\_Max), and then we present how this will change if the complex become compliant (Compliance) or if best available technology is implemented (BAT).

Using the mean measured pollutant flue gas concentrations across the existing units and the maximum guaranteed value for new units (Base), each year air pollution from the Banten-Suralaya complex leads to 1,470 (917–2,270) deaths (Figure 4), with the values in parentheses representing the 95 % confidence interval. If we instead use the maximum measured pollutant flue gas concentrations across existing units (Base\_Max), we find that air pollution from the Banten-Suralaya complex leads to 1,640 (1,020–2,570) deaths (Figure 4).

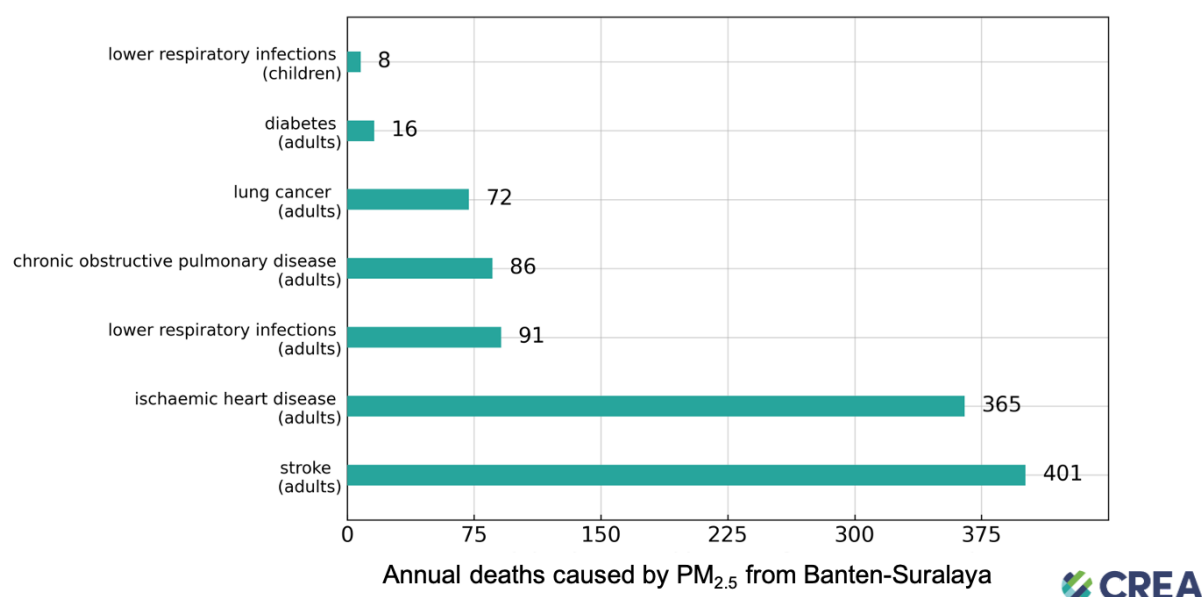


Source: CALPUFF model (Exponent, 2015) and health impact assessment (Myllyvirta, 2020)

**Figure 4. Impact of air pollution from Banten-Suralaya complex on all-cause mortality (thousand deaths each year)**

Figure 5 shows a breakdown of how PM<sub>2.5</sub> from the Banten-Suralaya complex leads to premature mortality through different diseases in adult and childhood populations in the Base\_Max scenario. PM<sub>2.5</sub> leads to 1,063 deaths, due to deaths among the adult population due to stroke (401), ischaemic heart disease (365), lower respiratory infections (91), chronic obstructive pulmonary disease (86), lung cancer (72), and diabetes (16), as well as in children under the age of 5, due to lower respiratory infections (8). But in addition to air pollution from the Banten-Suralaya complex causing deaths across the population, it also leads to a wide range of other illnesses.





Source: CALPUFF model (Exponent, 2015) and health impact assessment (Myllyvirta, 2020)

**Figure 5. Breakdown of cause-specific mortality rates for PM<sub>2.5</sub> mortality from Banten-Suralaya complex**

Table A2 shows the impacts of air pollution from the Banten-Suralaya complex on different morbidity health outcomes. Pregnant women are particularly susceptible to the negative impacts of pollution. Because of this, air pollution from the Banten-Suralaya complex leads to 936 (454–993) preterm births and 612 (190–1,060) low birth weights (Table A2). PM<sub>2.5</sub> and NO<sub>2</sub> also damage the respiratory system, and so emissions from this complex lead to 1,790, (1,070–2,500) asthma emergency room visits and 1,010 (230–2,190) new cases of asthma (Table A2). In response to the health morbidities, air pollution from the Banten-Suralaya complex is responsible for 742,000 (631,000–852,000) thousand days of work absences per year (Table A2). Overall, regardless of uncertainties in pollutant flue gas measurements (Base and Base\_Max), air pollution from the Banten-Suralaya complex has a profound impact on public health, including thousands of deaths (Figure 4), emergency room visits due to asthma, preterm births, and low birth weights (Table A2).

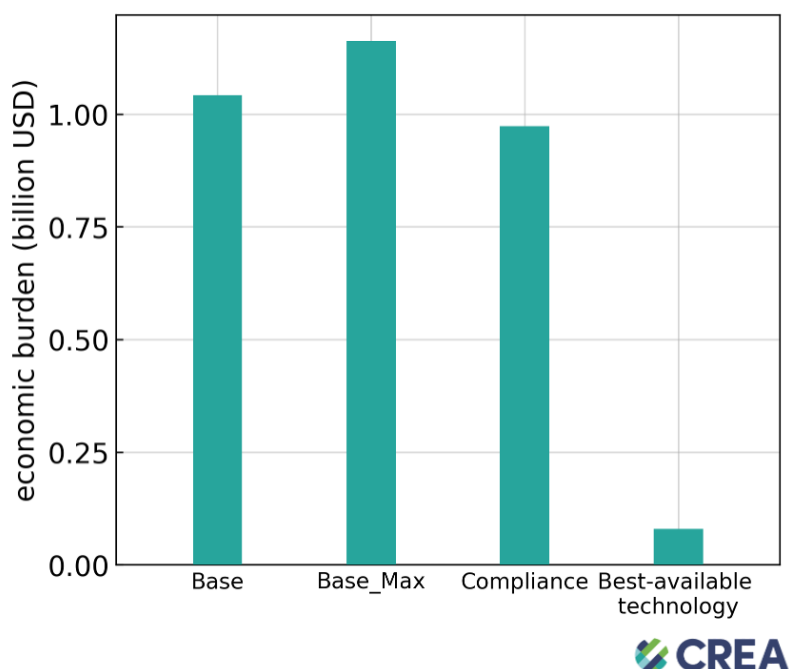
Achieving full compliance with national standards (Compliance), air pollution from the Banten-Suralaya complex will be responsible for 1,370 (853–2,140) deaths each year (Figure 4). This is equivalent to saving 97 lives per year if compared to the scenario using mean measured pollutant flue gas concentrations across existing units and the maximum guaranteed value for new units (Base), and a saving of 268 lives compared to the scenario

using maximum measured pollutant flue gas concentrations across existing units and the maximum guaranteed value for new units (Base\_Max). In addition to savings in deaths, achieving full compliance also leads to annual savings of 141–300 emergency room visits, 17–236 new asthma cases in children, 74–157 preterm births, 48–103 underweight births, and 59,000–125,000 work absences (Table A2).

Implementing best-available technology (BAT) in the Banten-Suralaya complex, air pollution from this source would be responsible for 113 (72–169) deaths each year. This is equivalent to saving 1,357 lives per year if compared to the scenario using mean measured pollutant flue gas concentrations across existing units and the maximum guaranteed value for new units (Base), and a saving of 1,527 lives if compared to the scenario using maximum measured pollutant flue gas concentrations across existing units and the maximum guaranteed value for new units (Base\_Max). In addition, implementing best available technology would (BAT) also leads to annual savings of 1,642–1,792 emergency room visits, 932–1,164 new asthma cases in children, 853–942 preterm births, 561–615 underweight births, and 680,000–746,000 work absences (Table A2).

## Pollutant economic impacts

We calculated the economic costs of the human health impacts of air pollution from the Banten-Suralaya complex for the scenarios shown in Table 1, and the results are shown in Figure 6 and Table A3. Using the mean measured pollutant flue gas concentrations across the existing units and the maximum guaranteed value for new units (Base), health outcomes due to air pollution from Banten-Suralaya cost the Indonesian economy USD 1.04 (0.65–1.60) billion each year, which is equivalent to IDR 14.2 (8.8–21.8) trillion. This large economic burden is mostly attributed to mortality, but also considers hospital costs of morbidities and the cost of work absences. If we instead use the maximum measured pollutant flue gas concentrations across the existing units (Base\_Max), health outcomes due to air pollution from the Banten-Suralaya complex cost the Indonesian economy USD 1.16 (0.72–1.80) billion each year, which is equivalent to IDR 15.8 (9.7–24.5) trillion. Overall, regardless of uncertainties in pollutant flue gas measurements (Base and Base\_Max), air pollution from the Banten-Suralaya complex has a devastating impact on the economy, costing several billion US dollars each year.



Source: CALPUFF model (Exponent, 2015) and health impact assessment (Myllyvirta, 2020)

**Figure 6. Health-related economic damages (billion USD each year) of air pollution from the Banten-Suralaya complex**

Note: Calculated by combining health outcomes from health impact assessment with economic valuations (Myllyvirta, 2020).

Achieving full compliance with national standards (Compliance), air pollution from the Banten-Suralaya complex will be responsible for health damages of USD 0.97 (0.6–1.5) billion each year, which is equivalent to IDR 13.2 (8.2–20.4) trillion. This is equivalent to annual economic savings of USD 70 million (IDR 940 billion) if we compare to the scenario where we use mean measured pollutant flue gas concentrations across existing units and the maximum guaranteed value for new units (*Base*), and USD 190 million (IDR 2.6 trillion) if we compare to the scenario where we use maximum measured pollutant flue gas concentrations across existing units and the maximum guaranteed value for new units (*Base\_Max*).

Implementing best-available technology (BAT) in the Banten-Suralaya complex, air pollution from this source would cause health costs of USD 0.08 (0.05–0.12) billion each year, which is equivalent to IDR 1.1 (0.7–1.6) trillion. This is equivalent to an annual

economic saving of USD 960 million (IDR 13.1 trillion) if we compare to the scenario where we use mean measured pollutant flue gas concentrations across existing units and the maximum guaranteed value for new units (Base), and USD 1.08 billion (IDR 14.7 trillion) if we compare to the scenario where we use maximum measured pollutant flue gas concentrations across existing units and the maximum guaranteed value for new units (*Base\_Max*).

## Discussion and relevance for Jakarta air quality

The contribution of coal-fired power plants (CFPPs) to regional air pollution (McDuffie et al., 2021) and the corresponding impacts of air pollution on human health and the economy have been established through decades of scientific peer-reviewed literature (Dockery et al., 1993). This scientific consensus has led to coal-fired power plants (CFPPs) being included in air pollution policies of municipal, national, and international governments, including China, the European Union, and the United States (Turnock et al., 2018, US EPA, 2011; Zhang et al., 2019). However, Indonesian government officials have recently played down the impact of coal-fired power plants (CFPPs) on air pollution, particularly in Jakarta.

The research in this health impact assessment (HIA) shows that the 6 GW Banten-Suralaya complex leads to annual mean  $\text{PM}_{2.5}$  concentrations of  $0.2\text{--}0.4\ \mu\text{g m}^{-3}$  in Jakarta (Figure 4). But Banten-Suralaya is only one of the many coal-fired power stations that affects air pollution in Jakarta. Previous research from CREA shows that other CFPPs have even larger contributions to annual mean  $\text{PM}_{2.5}$  levels in Jakarta, including Cikarang Babelan ( $1.5\ \mu\text{g m}^{-3}$ ), Indramayu ( $0.6\ \mu\text{g m}^{-3}$ ), Cilacap ( $0.6\ \mu\text{g m}^{-3}$ ), Lontar ( $0.5\ \mu\text{g m}^{-3}$ ), and Cirebon ( $0.5\ \mu\text{g m}^{-3}$ ) (Myllyvirta et al., 2023 a). Previous research also shows that air pollution from CFPPs leads to 2,500 deaths in the city of Jakarta (Myllyvirta et al., 2017), and 4,000 and 2,000 deaths in the provinces of West Java and Banten, respectively (Myllyvirta et al., 2023 b).

While some government officials have acknowledged the role of CFPPs on air pollution (TEMPO, 2023), others have downplayed it (Detik Finance, 2023). For instance, Erick Thohir, the Minister of State Owned Enterprises who oversees all state-owned companies, including PLN, claims that temporarily switching off Units 1-4 (total capacity 1.2 GW) did not affect air pollution in Jakarta (CNN Indonesia, 2023). In addition, the official briefing of the Ministry of Environment and Forestry held on 13 August 2023 to address the ongoing

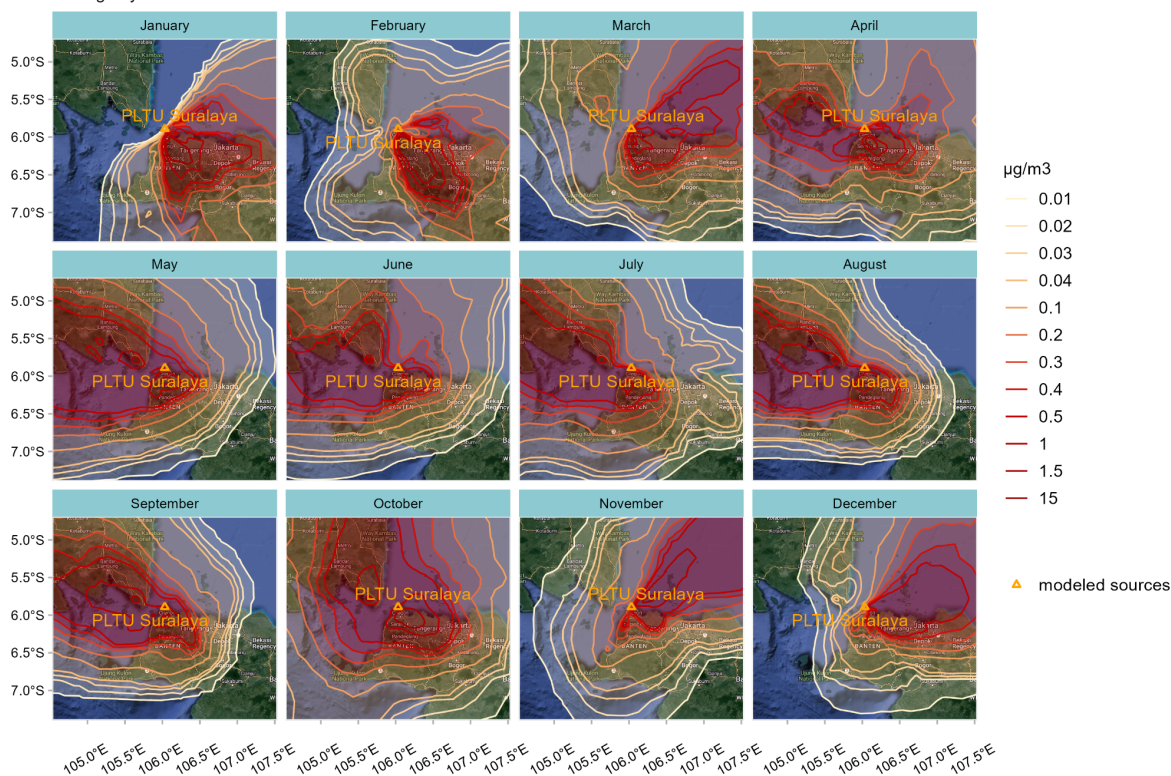
high pollution episode in the Jakarta Metropolitan Area, specifically mentioned the Banten Suralaya complex and presented satellite imagery that NO<sub>2</sub> emissions are dispersed by wind into the opposite direction of Jakarta, towards Sunda Strait (MOEF, 2023).

Insights shared by the Government in the recent months may mislead the public and allude to the conclusion that Banten-Suralaya power station, and CFPPs more generally, are not an important contributor to Jakarta's air pollution. CREA wishes to highlight that this conclusion is unsubstantiated due to the following reasons:

1. This shutdown represents a tiny fraction of the CFPPs that affect air pollution in Jakarta. This shutdown of 1.2 GW at the Banten-Suralaya complex represents only 20 % of the capacity of all units in existence and under construction at this complex (6 GW). Moreover, shutting down Banten-Suralaya only addresses one of the many CFPPs that contributes to pollution in Jakarta to an even greater extent (Cikarang Babelan, Indramayu, Cilacap, Lontar, and Cirebon).
2. The shutdown was likely performed in the season of the year where the contribution of Banten-Suralaya to Jakarta air pollution was lowest, leading to an underestimate of the impact of this complex on Jakartan public health. Figure 7 shows the seasonality of PM<sub>2.5</sub> from Banten-Suralaya (Figure A3 shows NO<sub>2</sub>). The overall impact of air pollution on human health risks is determined by the long-term exposure to air pollution (i.e. the annual average). Hence, by performing the shutdown during the period of the year where the contribution of Banten-Suralaya to Jakartan air pollution is at its lowest leads to an underestimate in the relationship between these power plants and human health.
3. If the decreased capacity in Units 1-4 was offset by increased capacity in the remaining CFPP units, then there would be no change in air pollution levels in Jakarta. Due to the lack of transparency in industrial emission reporting in Indonesia, however, the exact details of this shutdown are unclear.

### PM2.5 concentration from Banten-Suralaya coal power plant

average by month



Source: Simulated using CALPUFF (Exponent, 2015).

**Figure 7. Seasonality in PM2.5 from Banten-Suralaya complex**

Indonesian government officials have often evaluated or blamed air pollution on individual facilities or sources, such as Units 1-4 of Banten-Suralaya complex, transportation and meteorology (MOEF, 2023). However, air pollution originates from multiple different local and transboundary activities and is modulated by changes in meteorology (e.g. rainfall, wind direction). While this research highlights the importance of CFPPs on air pollution in Indonesia, it does not diminish the importance of other sources of air pollution, such as transport and biomass. Instead of blaming air pollution on individual contributing factors, such as transport or meteorology, Indonesian government officials instead need to acknowledge and target the multiple sources of air pollution from both local and transboundary regions through a comprehensive set of policies. These policies should begin with targeting the sources which have the largest body of scientific



evidence against them, including coal-fired power plants CFPPs, which are integral to the improvements in air pollution observed across Europe, North America and China.

## Methodology

### Pollutant flue gas concentrations

For the existing units, pollutant flue gas concentrations are taken from the United Nations Environment Programme (UNEP) report (UNEP, 2017). For the units under construction, we use the maximum pollutant flue gas concentrations, guaranteed by the emission control technology used in the units.

### Calculated pollutant emissions

We calculated pollutant emissions based on flue gas concentrations and flue gas volume for three different scenarios. In the Base scenario, we used measured pollutant flue gas concentrations for the units which already exist. For the units under construction, we used the conservative lower limit for estimates of pollutant flue gas concentrations that can be achieved with the emission mitigation technology used in these units. For the Compliance scenario, we use the pollutant flue gas concentrations for the Baseline scenario, but for any units that breach the national standards, we force them to be compliant. For the BAT scenario, we use pollutant flue gas concentrations measured in plants across Korea and Japan in which the BAT is implemented.

### Simulating pollutant atmospheric concentrations and deposition

We simulated air pollutant concentrations using the CALPUFF air dispersion model, version 7 (Exponent, 2015). CALPUFF is a widely-used industry standard model for long-range air quality impacts of point sources. The model has been evaluated extensively by the US Environmental Protection Agency, is open-source, and fully documented. CALPUFF calculates the atmospheric transport, dispersion, chemical transformation, and deposition of the pollutants, and the resulting incremental ground-level concentrations attributed to the studied emissions sources. Chemical transformations of SO<sub>2</sub> and NO<sub>2</sub> to PM<sub>2.5</sub> are calculated using ISORROPIA.

Background concentrations of oxidants (ozone, ammonia, hydrogen peroxide) are taken from a global atmospheric chemistry model. Meteorological input data for the year 2021



are generated from the Weather Research Forecasting (WRF) model (Skamarock et al., 2008), version 4.2.2. WRF was set up with 33 vertical levels and 2 nested grids. The mother nest has a grid resolution of 15 km, and spans ~1,500 km in both the north-south and east-west directions. The inner nest has a grid resolution of 5 km, spans ~300 km in both the north-south and east-west directions, and is centred over the Banten-Suralaya complex.

Mother and inner domains use a two-way nesting technique which ensures dynamic interaction between them. WRF simulations use initial and lateral boundary conditions from the National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFRS) dataset of the National Oceanic and Atmospheric Administration (NOAA) producing three-dimensional, hourly meteorological data covering the full calendar year of 2021.

For assessment of annual average pollutant concentrations, emissions are assumed constant throughout the year. Emissions from each of the ten units were modelled as separate area sources. The power plants were modelled as buoyant point sources, taking into account the stack height and thermal plume rise from the stacks. Stack characteristics were obtained from Universitas Indonesia (2012).

## **Estimated health and economic impacts of pollution**

We used our detailed and globally implementable health impact assessment (HIA) framework based on latest science to estimate the impacts of air pollution on human health. This framework includes as complete a set of health outcomes as possible without obvious overlaps.

The emphasis is on outcomes for which incidence data are available at the national level from global datasets and outcomes that have high relevance for healthcare costs and labour productivity. These health endpoints were selected and quantified in a way that enables economic valuation, adjusted by levels of economic output and income in different jurisdictions.

For each evaluated health outcome, we have selected a concentration-response relationship that has already been used to quantify the health burden of air pollution at the global level in peer-reviewed literature. This indicates the evidence is mature enough

to be applied across geographies and exposure levels. The calculation of health impacts follows a standard epidemiological calculation:

$$\Delta cases = Pop \times \sum_{age} \left[ Frac_{age} \times Incidence_{age} \times \frac{RR_{conc,age} - 1}{RR_{conc,age}} \right],$$

where Pop is the total population in the grid location; age is the analysed age group (in the case of age-dependent concentration-response functions, a 5-year age segment; in other cases, the total age range to which the function is applicable);  $Frac_{age}$  is the fraction of the population belonging to the analysed age group;  $Incidence_{age}$  is the baseline incidence of the analysed health condition; and conc is the pollutant concentration, with  $conc_{base}$  referring to the baseline concentration (current ambient concentration).  $RR_{(c, age)}$  is the function giving the risk ratio of the analysed health outcome at the given concentration for the given age group compared with clean air. In the case of a log-linear, non-age-specific concentration-response function, the RR function becomes:

$$RR(c) = [RR_0 \times c] - [c_0 \times \Delta c_0], \text{ when } c > c_0$$

Data on total population and population age structure were taken from Global Burden of Disease results for 2019 (Global Burden of Disease, 2020), which was accessed from the Institute for Health Metrics and Evaluation (IHME) (IHME, 2020). The spatial distribution of population within each city and country, as projected for 2020, was based on the Gridded Population of the World v4 from the Center for International Earth Science Information Network (CIESIN) (CIESIN, 2018).

Following the update of WHO Air Quality Guidelines, which now recognise health harm from  $NO_2$  at low concentrations, we use the mortality risk function for  $NO_2$  based on the findings of Huangfu and Atkinson (2020), and including impacts down to  $4.5 \mu g/m^3$ , the lowest concentration level in studies that found increased mortality risk (Table 2).

Adult deaths were estimated using the risk functions developed by Burnett et al. (2018), as applied by Lelieveld et al. (2019). Deaths of small children (under 5 years old) from lower respiratory infections linked to  $PM_{2.5}$  pollution were assessed using the Global Burden of Disease risk function for lower respiratory diseases (IHME, 2020). For all mortality results, cause-specific data were taken from the Global Burden of Disease project results for 2019 (IHME, 2020).

Health impact modelling projects the effects of pollutant exposure during the study year. Some health impacts are immediate, such as exacerbation of asthma symptoms and lost working days, whereas other chronic impacts may have a latency of several years. Concentration-response relationships for emergency room visits for asthma and work absences were based on studies that evaluated daily variations in pollutant concentrations and health outcomes; these relationships were applied to changes in annual average concentrations. The annual average baseline concentrations of PM<sub>2.5</sub> and NO<sub>2</sub> were taken from van Donkelaar et al. (2021) and Larkin et al. (2017), respectively. Since the no-harm concentration for SO<sub>2</sub> is very low and the risk function is linear with respect to the background concentration, there was no need for data on SO<sub>2</sub> background concentrations.

The development of the health impacts into the future took into account projected changes in population, population age structure and mortality by age group, based on the UNPD (2019) World Population Prospects Medium Variant. This factors in the expected reduction in baseline infant mortality and increase in premature deaths from chronic diseases in older adults as a part of the population and epidemiological transitions and improvements in health care.

**Table 2. Input parameters and data used in estimating physical health impacts**

Age group	Effect	Pollutant	Concentration-response function	Concentration change	No-risk threshold	Reference	Incidence data
1-18	New asthma cases	NO <sub>2</sub>	1.26 (1.10 – 1.37)	10 ppb	2 ppb	Khreis et al. (2017)	Achakulwisut et al. (2019)
0-17	Asthma emergency room visits	PM <sub>2.5</sub>	1.025 (1.013 – 1.037)	10 µg/m <sup>3</sup>	6 µg/m <sup>3</sup>	Zheng et al. (2015)	Anenberg et al. (2018)
18-99	Asthma emergency room visits	PM <sub>2.5</sub>	1.023 (1.015 – 1.031)	10 µg/m <sup>3</sup>	6 µg/m <sup>3</sup>	Zheng et al. (2015)	Anenberg et al. (2018)
Newborn	Preterm birth	PM <sub>2.5</sub>	1.15 (1.07 – 1.16)	10 µg/m <sup>3</sup>	8.8 µg/m <sup>3</sup>	Sapkota et al. (2012)	Chawanpaiboon et al. (2018)
20-65	Work absence	PM <sub>2.5</sub>	1.046 (1.039 – 1.053)	10 µg/m <sup>3</sup>	N/A	WHO (2013)	EEA (2014)
0-4	Deaths from lower respiratory infections	PM <sub>2.5</sub>	IHME (2020)		5.8 µg/m <sup>3</sup>	IHME (2020)	IHME (2020)
25-99	Deaths from non-communicable diseases, disaggregated by cause, and from lower respiratory infections	PM <sub>2.5</sub>	Burnett et al. (2018)		2.4 µg/m <sup>3</sup>	Burnett et al. (2018)	IHME (2020)

25-99	Disability caused by diabetes, stroke and chronic respiratory disease	PM <sub>2.5</sub>	IHME (2020)		2.4 µg/m <sup>3</sup>	Burnett et al. (2018)	IHME (2020)
25-99	Premature deaths	NO <sub>2</sub>	1.02 (1.01 – 1.04)	10 µg/m <sup>3</sup>	4.5 µg/m <sup>3</sup>	Huangfu & Atkinson. (2020); NRT from Stieb et al. (2021)	IHME (2020)
25-99	Premature deaths	SO <sub>2</sub>	1.02 (1.01–1.03)	5 ppb	0.02 ppb	Krewski et al. 2009	IHME 2020

Note: Numeric values in the column ‘Concentration-response function’ refer to odds ratio corresponding to the increase in concentrations given in the column ‘concentration change’. Literature references indicate the use of a non-linear concentration-response function. No-harm threshold refers to a concentration below which the health impact is not quantified, generally because the studies on which the function is based did not include people with lower exposure levels. Data on concentration-response relationships do not exist for all geographies, so a global risk model is applied to all cities. Incidence data are generally unavailable at the city level so national averages have to be applied.

Air pollution both increases the risk of developing respiratory and cardiovascular diseases, and increases complications from them, significantly lowering the quality of life and economic productivity of people affected, and increasing healthcare costs. Economic losses due to air pollution were calculated using the methods outlined in Myllyvirta et al. (2020). The valuation of deaths was updated to the values derived by Viscusi and Masterman (2017), which are based on labour market data, and pay particular attention to applicability in middle- and low-income countries. The Global Burden of Disease project has quantified the degree of disability caused by each disease into a ‘disability weight’ that can be used to compare the costs of different illnesses. The economic cost of disability and reduced quality of life caused by these diseases and disabilities are assessed based on disability weights, combined with the economic valuation of disability used by the UK environmental regulator DEFRA (Birchby et al., 2019), and adjusted by GNI PPP for Indonesia. The deaths of young children are valued at twice the valuation of adult deaths, following the recommendations of the OECD (2012).

The valuation of future health impacts is based on the premise that the long-term social discount rate is equal to long-term GDP growth rate, and the economic loss associated with different health impacts is proportional to the GDP, resulting in a constant present value of health impacts over time.

**Table 3. Input parameters and data used to estimate economic costs of health impacts**

Outcome	Valuation at world average GDP/GNI per capita, 2017 international dollars	Valuation in Indonesia, current USD	Reference
Work absence (sick leave days)	85	335,300	EEA (2014)
Number of children suffering from asthma due to pollution exposure (increased prevalence)	1,077	4,228,000	Brandt et al. (2012)
Deaths	2,637,000	10,260,000,000	Viscusi & Masterman (2017)
Deaths of children under 5	5,273,000	20,510,000,000	OECD (2012)
Asthma emergency room visits	232	911,800	Brandt et al. (2012)
Preterm births	107,700	422,800,000	Trasande et al. (2016)
Years lived with disability	28,480	110,800,000	Birchby et al. (2019)

Sources: EEA (2014), Brandt et al. (2012), Viscusi & Masterman (2017), OECD (2012), Brandt et al. (2012), Trasande et al. (2016), Birchby et al. (2019)

## References

Achakulwisut, P., Brauer, M., Hystad, P. and Anenberg, S. C. (2019). Global, National, and Urban Burdens of Paediatric Asthma Incidence Attributable to Ambient NO<sub>2</sub> Pollution: Estimates from Global Datasets. *Lancet*, 3 (4): E166-E178.

[https://doi.org/10.1016/S2542-5196\(19\)30046-4](https://doi.org/10.1016/S2542-5196(19)30046-4)

AQLI. (2019). Indonesia's Worsening Air Quality and its Impact on Life Expectancy.

<https://aqli.epic.uchicago.edu/wp-content/uploads/2019/03/Indonesia-Report.pdf>

AQLI (2021). Indonesia's Air Pollution and its Impact on Life Expectancy.

[https://aqli.epic.uchicago.edu/wp-content/uploads/2021/09/AQLI\\_Indonesia\\_Report.English.pdf](https://aqli.epic.uchicago.edu/wp-content/uploads/2021/09/AQLI_Indonesia_Report.English.pdf)

AQLI. (2022). The 2008 Olympics to the 2022 Olympics China's Fight to Win its War Against Pollution.

[https://aqli.epic.uchicago.edu/wp-content/uploads/2022/02/China-Report\\_FEB2022-2.pdf](https://aqli.epic.uchicago.edu/wp-content/uploads/2022/02/China-Report_FEB2022-2.pdf)

Anenberg, S. C, Henze, D. K., Tinney, V., Kinney, P. L, Raich, W., Fann, N., Malley, C. S., Roman, H., Lamsal, L., Duncan, B., Martin, R. V., van Donkelaar, A., Brauer, M., Doherty, R., Jonson, J. E., Davila, Y., Sudo, K. and Kuylensstierna, J. C. I. (2018). Estimates of the Global Burden of Ambient PM<sub>2.5</sub>, Ozone, and NO<sub>2</sub> on Asthma Incidence and Emergency Room Visits. *Environmental Health Perspectives*, 126 (10). <https://doi.org/10.1289/EHP3766>

Anhäuser, A., Son, M., Farrow, A. and Myllyvirta, L. (2019). Health Impacts of Units 9-10 of the Jawa Coal-fired Power Plant in Banten, Indonesia. *Greenpeace*.

<https://www.marketforces.org.au/wp-content/uploads/2019/12/Korean-Jawa-9-10-Health-Impacts-compressed.pdf>

Betahita. (2020). Walhi Gugat Izin PLTU Jawa 9 dan 10 ke PTUN Banten. 09 November, 2020. [Last accessed: 11 April, 2023]

<https://betahita.id/news/detail/5750/walhi-gugat-izin-pltu-jawa-9-dan-10-ke-ptun-banten.html?v=1604920882>

- Birchby, D., Stedman, J., Whiting, S. and Vedrenne, M. (2019). Air Quality Damage Cost Update 2019. 2019. Ricardo/ED59323/Issue Number 2.0. [https://uk-air.defra.gov.uk/assets/documents/reports/cat09/1902271109\\_Damage\\_cost\\_update\\_2018\\_FINAL\\_Issue\\_2\\_publication.pdf](https://uk-air.defra.gov.uk/assets/documents/reports/cat09/1902271109_Damage_cost_update_2018_FINAL_Issue_2_publication.pdf)
- Brandt, S.J., Perez, L., Künzli, N., Lurmann, F. and McConnell, R. (2012). Costs of childhood asthma due to traffic-related pollution in two California communities. *European Respiratory Journal*, 40(2): 363-370. <https://doi.org/10.1183/09031936.00157811>
- Burnett, R., Chen, H., Szyszkowicz, M., Fann, N., Hubbell, B., et al. (2018). Global Estimates of Mortality Associated with Long-Term Exposure to Outdoor Fine Particulate Matter. *Proceeding of the National Academies of Science*, 115 (38): 9592-9597. <https://doi.org/10.1073/pnas.1803222115>
- Chawanpaiboon, S., Vogel, J. P., Moller, A., Lumbiganon, P., Petzold, M., Hogan, D., Landoulsi, S., Jampathong, N., Kongwattanakul, K., Laopaiboon, M., Lewis, C., Rattanakanokchai, S., Teng, D. T., Thinkhamrop, J., Watananirun, K., Zhang, J., Zhou, W. and Gülmezoglu, A. M. (2018). Global, Regional, and National Estimates of Levels of Preterm Birth in 2014: A Systematic Review and Modelling Analysis. *Lancet Global Health*, 2018. [https://doi.org/10.1016/S2214-109X\(18\)30451-0](https://doi.org/10.1016/S2214-109X(18)30451-0)
- CIESIN. (2018). Gridded Population of the World, Version 4 (GPWv4): Population Density Adjusted to Match 2015 Revision UN WPP Country Totals, Revision 11. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC), 2018. <https://doi.org/10.7927/H4F47M65>
- CNN Indonesia. (2023). Erick Thohir Buka Suara soal PLTU Terkait Polusi. <https://www.cnnindonesia.com/ekonomi/20230831202551-85-993192/erick-thohir-buka-suara-soal-pltu-terkait-polusi>
- Darussalam, J. S. (2022). Izin PLTU Jawa 9 & 10 yang Diterbitkan Wahidin Halim Cacat Hukum, WALHI: Proyek Ini Hanya Akan Mendatangkan Mudarat. HitsBanten, 6 August, 2020. [Last accessed: 11 April, 2023] <https://bantenhits.com/2020/08/06/izin-pltu-jawa-9-10-yang-diterbitkan-wahidin-halim-cacat-hukum-walhi-proyek-ini-hanya-akan-m mendatangkan-mudarat/>



Di, Q., Wang, Y., Zanobetti, A., Wang, Y., Koutrakis, P., Choirat, C., Dominici, F. and Schwartz, J. (2017). Air Pollution and Mortality in the Medicare Population. *New England Journal of Medicine*, 376: 2513-2522. [10.1056/NEJMoa1702747](https://doi.org/10.1056/NEJMoa1702747)

Detik Finance (2023). PLTU Suralaya Disuntik Mati, Erick Thohir: Ternyata Tidak Mengurangi Polusi  
<https://finance.detik.com/energi/d-6906317/pltu-suralaya-disuntik-mati-erick-thohir-ternyata-tidak-mengurangi-polusi>

Dockery et al. (1993). An Association between Air Pollution and Mortality in Six U.S. Cities. *New England Journal of Medicine*. [10.1056/NEJM199312093292401](https://doi.org/10.1056/NEJM199312093292401)

Donkelaar, van A., Hammer, M. S., Bindle, L., Brauer, M., Brook, J. R., Garay, M. J., Hu, N. C., Kalashnikova, O. V., Khan, R. A., Lee, C., Levy, R. C., Lyapustin, A., Sayer, A. M. and Martin, R. V. (2021). Monthly Global Estimates of Fine Particulate Matter and Their Uncertainty. *Environmental Science & Technology*, 55 (22): 15287-15300.  
<https://doi.org/10.1021/acs.est.1c05309>

European Environment Agency (EEA). (2014). Costs of air pollution from European industrial facilities 2008–2012 — an updated assessment. EEA Technical report No 20/2014.  
<https://www.eea.europa.eu/publications/costs-of-air-pollution-2008-2012>

EMBER. (2022). Indonesia. Countries & regions. [Last accessed: 11 April, 2023]  
<https://ember-climate.org/countries-and-regions/countries/indonesia/>

EMBER. (2021). Top 25 Coal Power Countries in 2020. Insights, 14 April, 2021.  
<https://ember-climate.org/insights/research/top-25-coal-power-countries-in-2020/>

Exponent. (2015). CALPUFF Modeling System. <http://www.src.com>

Global Burden of Disease. (2020). Global Burden of 87 Risk Factors in 204 Countries and Territories, 1990–2019: A Systematic Analysis for the Global Burden of Disease Study 2019. *Lancet*, 396 (10258): P1223-1249. [doi.org/10.1016/S0140-6736\(20\)30752-2](https://doi.org/10.1016/S0140-6736(20)30752-2)

GEM. (2022). Boom and Bust Coal 2022 – Tracking the Global Coal Plant Pipeline. Global Energy Monitor, CREA, E3G, Sierra Club, SFOC, Kiko Network, CAN Europe, LIFE and Bangladesh Groups. <https://globalenergymonitor.org/report/boom-and-bust-coal-2022/>

GEM. (2023a). Global Coal Plant Tracker. <https://globalenergymonitor.org/projects/global-coal-plant-tracker/>

GEM. (2023b). Banten Suralaya power station. [https://www.gem.wiki/Banten\\_Suralaya\\_power\\_station#cite\\_note-mb-29](https://www.gem.wiki/Banten_Suralaya_power_station#cite_note-mb-29)

Greenpeace. (2017). Jakarta's silent killer. How the city's dangerous levels of air pollution are about to get even worse. <https://www.greenpeace.org/static/planet4-southeastasia-stateless/2020/10/48d34259-jakarta-silent-killer-report-oct-24-2017-1.pdf>

Huangfu, P. and Atkinson, R. (2020). Long-Term Exposure to NO<sub>2</sub> and O<sub>3</sub> and All-Cause and Respiratory Mortality: A Systematic Review and Meta-Analysis. *Environment International*, 144, 105998. <https://doi.org/10.1016/j.envint.2020.105998>

IESR (2023). Delivering Indonesia's Power Sector Transition. <https://iesr.or.id/en/pustaka/delivering-indonesias-power-sector-transition>

Institute for Health Metrics and Evaluation (IHME) (2020). GBD Results. <http://ghdx.healthdata.org/gbd-results-tool>

International Energy Agency (2012). Technology Roadmap for High Efficiency Low Emissions Coal Fired Power Generation. [https://iea.blob.core.windows.net/assets/c43bc244-0050-45ec-807c-d870ae9241a7/TechnologyRoadmapHighEfficiencyLowEmissionsCoalFiredPowerGeneration\\_WEB\\_Updated\\_March2013.pdf](https://iea.blob.core.windows.net/assets/c43bc244-0050-45ec-807c-d870ae9241a7/TechnologyRoadmapHighEfficiencyLowEmissionsCoalFiredPowerGeneration_WEB_Updated_March2013.pdf)

Jong, H. N. (2018). Activists urge end to South Korean funding of Indonesia coal plants. Mongabay, 16 November, 2018. [Last accessed: 11 April, 2023] <https://news.mongabay.com/2018/11/activists-urge-end-to-south-korean-funding-of-indonesia-coal-plants/>

Kelly (2021). Air pollution and chronic bronchitis: the evidence firms up. *Thorax*. 76(8): 744–745. <https://doi.org/10.1136%2Fthoraxjnl-2021-216883>

Khreis, H., Kelly, C., Tate, J., Parslow, R., Lucas, K. and Nieuwenhuijsen, M. (2017). Exposure to traffic-related air pollution and risk of development of childhood asthma: A systematic review and meta-analysis. *Environmental International*, 100: 1-31. <https://doi.org/10.1016/j.envint.2016.11.012>

Kopplitz, S. N., Jacob, D. J., Sulprizio, M. P., Myllyvirta, L. and Reid, C. (2017). Burden of Disease from Rising Coal-Fired Power Plant Emissions in Southeast Asia. *Environmental Science & Technology*, 51 (3): 1467-1476. <https://doi.org/10.1021/acs.est.6b03731>

Krewski, D., Jerrett, M., Burnett, R. T., Ma, R., Hughes, E., Shi, Y., Turner, M. C., Pope 3rd, C. A., Thurston, G., Calle, E. E., Thun, M. J., Beckerman, B., DeLuca, P., Finkelstein, N., Ito, K., Moore, D. K., Newbold, K. B., Ramsay, T., Ross, Z., Shin, H. and Tempalski, B. (2009). Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality. *Research Reports Health Effects Institute*, 140: 5-114. PMID: 19627030.

Larkin, A., Geddes, J. A., Martin, R. V., Xiao, Q., Liu, Y., Marshall, J. D., Brauer, M. and Hystad, P. (2017). Global Land Use Regression Model for Nitrogen Dioxide Air Pollution. *Environmental Science & Technology*, 51 (12): 6957-6964. <https://dx.doi.org/10.1021/acs.est.7b01148>

Lelieveld, J., Klingmüller, K., Pozzer, A., Burnett, R. T., Haines, A. and Ramanathan, V. (2019). Effects of fossil fuel and total anthropogenic emission removal on public health and climate. *Proceedings of the National Academies of Science*, 116 (15): 7192-7197. <https://doi.org/10.1073/pnas.1819989116>

Levy, J. I., Wilson, A. M. and Zwack, L. M.. (2007). Quantifying the Efficiency and Equity Implications of Power Plant Air Pollution Control Strategies in the United States. *Environmental Health Perspectives*, 115 (5). <https://doi.org/10.1289/ehp.9712>

McDuffie, E. E., Martin, R. V., Spadaro, J. V., Burnett, R., Smith, S. J., O'Rourke, P., Hammer, M. S., Donkelaar, van A., Bindle, L., Shah, V., Jaeglé, L., Luo, G., Yu, F., Adeniran, J. A., Lin, J. and Brauer, M. (2021). Source sector and fuel contributions to ambient PM<sub>2.5</sub> and attributable mortality across multiple spatial scales. *Nature Communications*, 12 (3594). [doi.org/10.1038/s41467-021-23853-y](https://doi.org/10.1038/s41467-021-23853-y)

Ministry of Environment and Forestry (MOEF) - Kementerian Lingkungan Hidup dan Kehutanan. (2023, August 13). Media Briefing: Kualitas Udara di Wilayah JABODETABEK [Video]. YouTube. <https://www.youtube.com/watch?v=nxrnjneJnNA>

Myllyvirta, L. & Chuwah, C. (2017). Assessing the air quality, toxic and health impacts of coal-fired power plants surrounding the Jakarta megacity. Greenpeace Research Laboratories Technical Report 07-2017. September 2017. <https://www.greenpeace.to/greenpeace/wp-content/uploads/2018/01/GRL-TR-07-2017-Jakarta.pdf>

Myllyvirta, L., Suarez, I., Uusivuori, E. and Thieriot, H. (2020). Transboundary Air Pollution in the Jakarta, Banten, and West Java provinces. CREA. [https://energyandcleanair.org/wp/wp-content/uploads/2020/08/Jakarta-Transboundary-Pollution\\_FINALEnglish.pdf](https://energyandcleanair.org/wp/wp-content/uploads/2020/08/Jakarta-Transboundary-Pollution_FINALEnglish.pdf)

Myllyvirta et al. (2023 a). Work From Home (WFH) and other gimmicks cannot clear Jakarta's air. <https://energyandcleanair.org/work-from-home-wfh-and-other-gimmicks-cannot-clear-jakartas-air/>

Myllyvirta et al. (2023 b). Health benefits of Just Energy Transition and coal phase-out in Indonesia. <https://energyandcleanair.org/publication/health-benefits-of-just-energy-transition-and-coal-phase-out-in-indonesia/>

OECD. (2012). Mortality Risk Valuation in Environment, Health and Transport Policies. <https://doi.org/10.1787/9789264130807-en>

Pun, V. C., Mehta, S. and Lestari, P. (2020). Main Sources of Air Pollution in DKI Jakarta. [https://www.researchgate.net/publication/345652195\\_Main\\_Sources\\_of\\_Air\\_Pollution\\_in\\_DKI\\_Jakarta#fullTextFileContent](https://www.researchgate.net/publication/345652195_Main_Sources_of_Air_Pollution_in_DKI_Jakarta#fullTextFileContent)

PLN (2020). Kondisi Pemenuhan Emisi Pembangkit PLN (draft).

Reddington, C. L., Yoshioka, M., Balasubramanian, R., Ridley, D., Toh, Y. Y., Arnold, S. R. and Spracklen, D. V. (2014). Contribution of vegetation and peat fires to particulate air pollution in Southeast Asia. *Environmental Research Letters*, 9 (094006).

<https://iopscience.iop.org/article/10.1088/1748-9326/9/9/094006/pdf>

Roman, H. A., Walsh, T. L., Coull, B. A., Dewailly, É., Guallar, E., Harris, D., Mariën, K., Schwartz, J., Stern, A. H., Virtanen, J. K. and Rice, G. (2011). Evaluation of the Cardiovascular Effects of Methylmercury Exposures: Current Evidence Supports Development of a Dose-Response Function for Regulatory Benefits Analysis. *Environmental Health Perspectives*, 119 (5). [doi.org/10.1289/ehp.1003012](https://doi.org/10.1289/ehp.1003012)

Sapkota, A., Chelikowsky, A. P., Nachman, K. E., Cohen, A. J. and Ritz, B. (2012). Exposure to particulate matter and adverse birth outcomes: a comprehensive review and meta-analysis. *Air Quality, Atmosphere & Health*, 5: 369-381.

<https://doi.org/10.1007/s11869-010-0106-3>

Shi, L., Wu, X., Yazdi, M. D., Braun, D., Awad, Y. A., Wei, Y., Liu, P., Di, Q., Wang, Y., Schwartz, J., Dominici, F., Kioumourtzoglou, M-A. and Zanobetti, A. (2020). Long-term effects of PM<sub>2.5</sub> on neurological disorders in the American Medicare population: a longitudinal cohort study. *Lancet Planetary Health*, 4 (12): E557-E565. [doi: 10.1016/S2542-5196\(20\)30227-8](https://doi.org/10.1016/S2542-5196(20)30227-8)

Shi, L., Zhu, Q., Wang, Y., Hao, H., Zhang, H., Schwartz, J., Amini, H., Donkelaar, van A., Martin, R. V., Steenland, K., Sarnat, J. A., Caudle, W. M., Ma, T., Li, H., Chang, H. H., Li, J. Z., Wingo, T., Mao, X., Russell, A. G., Weber, R. J. and Liu, P. (2023). Incident dementia and long-term exposure to constituents of fine particle air pollution: A national cohort study in the United States. *Proceeding of the National Academies of Science*, 120 (1), E2211282119.

<https://doi.org/10.1073/pnas.2211282119>

Skamarock, W. C., Klemp, J. B., Dudhia, J., Gill, D. O., Barker, D., Duda, M.G., et al. (2008). A Description of the Advanced Research WRF Version 3. University Corporation for Atmospheric Research. [doi:10.5065/D68S4MVH](https://doi.org/10.5065/D68S4MVH)

Stieb D. M., Berjawi, R., Emode, M., Zheng, C., Salama, D., Hocking, R., Lyrette, N., Matz, C., Lavigne, E. and Shin, H. H. (2021). Systematic review and meta-analysis of cohort studies of long term outdoor nitrogen dioxide exposure and mortality. *PLoS ONE*, 16 (2): e0246451. <https://doi.org/10.1371/journal.pone.0246451>

Syuhada et al., (2023). Impacts of Air Pollution on Health and Cost of Illness in Jakarta, Indonesia. <https://doi.org/10.3390/ijerph20042916>

TEMPO (2023). Jakarta Air Pollution; 11 Power Plants Subject to Sanctions, Says Minister.  
<https://en.tempo.co/read/1765784/jakarta-air-pollution-11-power-plants-subject-to-sanctions-says-minister>

Trasande, L., Malecha, P. and Attina, T. M. (2016). Particulate Matter Exposure and Preterm Birth: Estimates of U.S. Attributable Burden and Economic Costs. *Environmental Health Perspectives*, 124 (12).  
<https://doi.org/10.1289/ehp.1510810>

Turnock, S. T., Butt, E. W., Richardson, T. B., Mann, G. W., Reddington, C. L., Forster, P. M., Haywood, J., Crippa, M., Janssens-Maenhout, G., Johnson, C. E., Bellouin, N., Carslaw, K. S. and Spracklen, D. V. (2018). The impact of European legislative and technology measures to reduce air pollutants on air quality, human health and climate. *Environmental Research Letters*, 11, 024010. <http://dx.doi.org/10.1088/1748-9326/11/2/024010>

UNEP. (2017). Final report mercury emissions from coal-fired power plants in Indonesia. Report prepared by: Basel Convention Regional Centre for South East Asia/Stockholm Convention Regional Centre Indonesia Jakarta, Indonesia. December 2017.  
<https://wedocs.unep.org/bitstream/handle/20.500.11822/22713/1.%20Report%20Mercury%20Emission%20FINAL%20-%20Copy.pdf?sequence=1&isAllowed=y>

Universitas Indonesia (2012). Pola Keruangan Emisi Karbondioksida Pembangkit Listrik Tenaga Uap Di Provinsi Banten.  
<https://lib.ui.ac.id/file?file=digital/20296549-S1875-Dian%20Anggraeni.pdf>

United Nations, Department of Economic and Social Affairs, Population Division (UNPD). (2019). World Population Prospects 2019, Online Edition. Rev. 1.

US EPA. Benefits and costs of the Clean Air Act 1990–2020, the second prospective study.

<https://www.epa.gov/clean-air-act-overview/benefits-and-costs-clean-air-act-1990-2020-second-prospective-study>

Viscusi, W. K. and Masterman, C. J. (2017). Income Elasticities and Global Values of a Statistical Life. *Journal of Benefit-Cost Analysis*, 8 (2): 226-250.  
<https://doi.org/10.1017/bca.2017.12>

Vohra, K., Marais, E. A., Bloss, W. J., Schwartz, J., Mickley, L. J., Damme, van M., Clarisse, L. and Coheur, P-F. (2022). Rapid rise in premature mortality due to anthropogenic air pollution in fast-growing tropical megacities from 2005 to 2018. *Science Advances*, 8, eabm4435. <https://www.science.org/doi/epdf/10.1126/sciadv.abm4435>

The White House. (2022). Indonesia and International Partners Secure Groundbreaking Climate Targets and Associated Financing. Statements and Releases. [Last accessed: 11 April, 2023]  
<https://www.whitehouse.gov/briefing-room/statements-releases/2022/11/15/indonesia-and-international-partners-secure-groundbreaking-climate-targets-and-associated-financing/>

The World Bank. (2022a). The World Bank In Indonesia.  
<https://www.worldbank.org/en/country/indonesia/overview>

The World Bank. (2022b). The Global Health Cost of PM<sub>2.5</sub> Air Pollution: A Case for Action Beyond 2021. <https://elibrary.worldbank.org/doi/abs/10.1596/978-1-4648-1816-5>

World Health Organization (WHO) (2013). WHO: Health Risks of Air Pollution in Europe-HRAPIE Project.  
[https://www.euro.who.int/\\_data/assets/pdf\\_file/0006/238956/Health\\_risks\\_air\\_pollution\\_HRAPIE\\_project.pdf](https://www.euro.who.int/_data/assets/pdf_file/0006/238956/Health_risks_air_pollution_HRAPIE_project.pdf)

WHO. (2021). WHO global air quality guidelines: particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide.  
<https://apps.who.int/iris/bitstream/handle/10665/345329/9789240034228-eng.pdf>

Xue, T., Guan, T., Zheng, Y., Geng, G., Zhang, Q., Yao, Y. and Zhu, T. (2021). Long-term PM<sub>2.5</sub> exposure and depressive symptoms in China: A quasi-experimental study. *Lancet*, 6, 100079. <https://doi.org/10.1016/j.lanwpc.2020.100079>

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Zhang et al. (2019). Drivers of improved PM<sub>2.5</sub> air quality in China from 2013 to 2017. *PNAS*, <https://doi.org/10.1073/pnas.1907956116>

Zhang, Y., Song, Z., Huang, S., Zhang, P., Peng, Y., Wu, P., Dutkiewicz, S., Zhang, H., Wu, S., Wang, F., Chen, L., Wang, and Li, P. (2021). Global health effects of future atmospheric mercury emissions. *Nature Communications*, 12 (3035).  
[doi.org/10.1038/s41467-021-23391-7](https://doi.org/10.1038/s41467-021-23391-7)

Zhang et al. (2021). Ambient air pollutants and hospital visits for pneumonia: a case-crossover study in Qingdao, China. *BMC Public Health*.  
<https://doi.org/10.1186/s12889-020-10065-0>

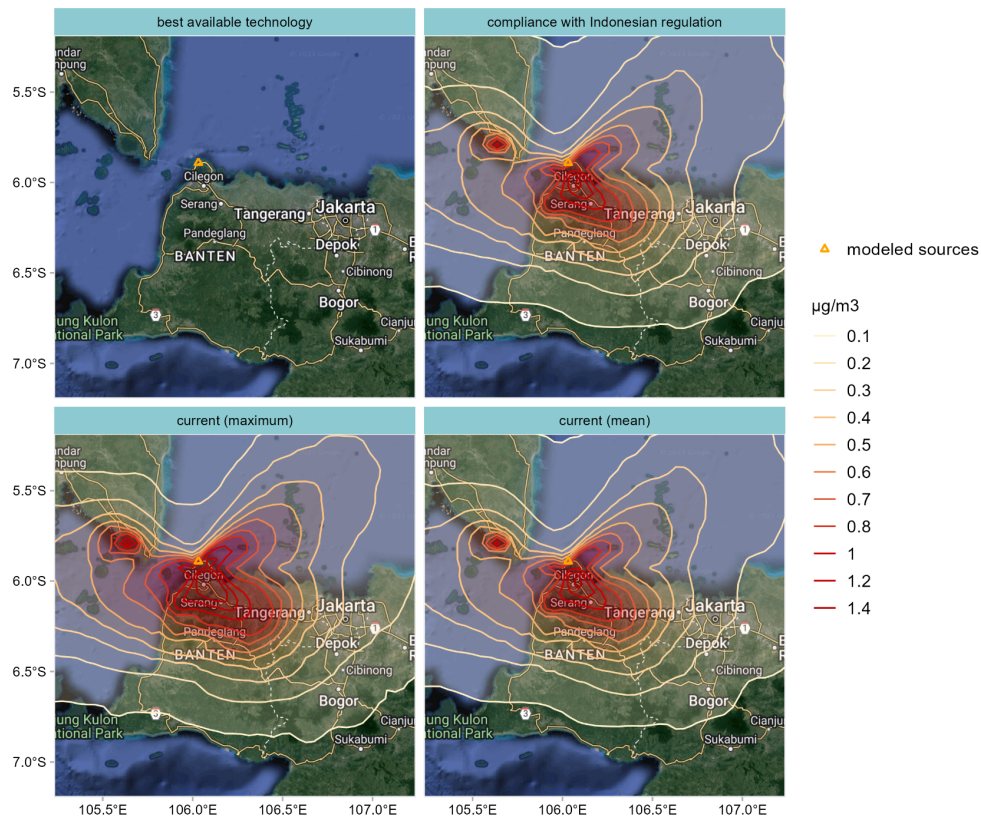
Zheng, X., Ding, H., Jiang, L., Chen, S., Zheng, J., Qiu, M., Zhou, Y., Chen, Q. and Guan, W. (2015). Association between Air Pollutants and Asthma Emergency Room Visits and Hospital Admissions in Time Series studies: A Systematic Review and Meta-Analysis. *PLoS One*, 10(9): e0138146. <https://doi.org/10.1371/journal.pone.0138146>



## Appendix

### Annual mean NO<sub>2</sub> concentration from Banten Suralaya complex

by scenario



CREA

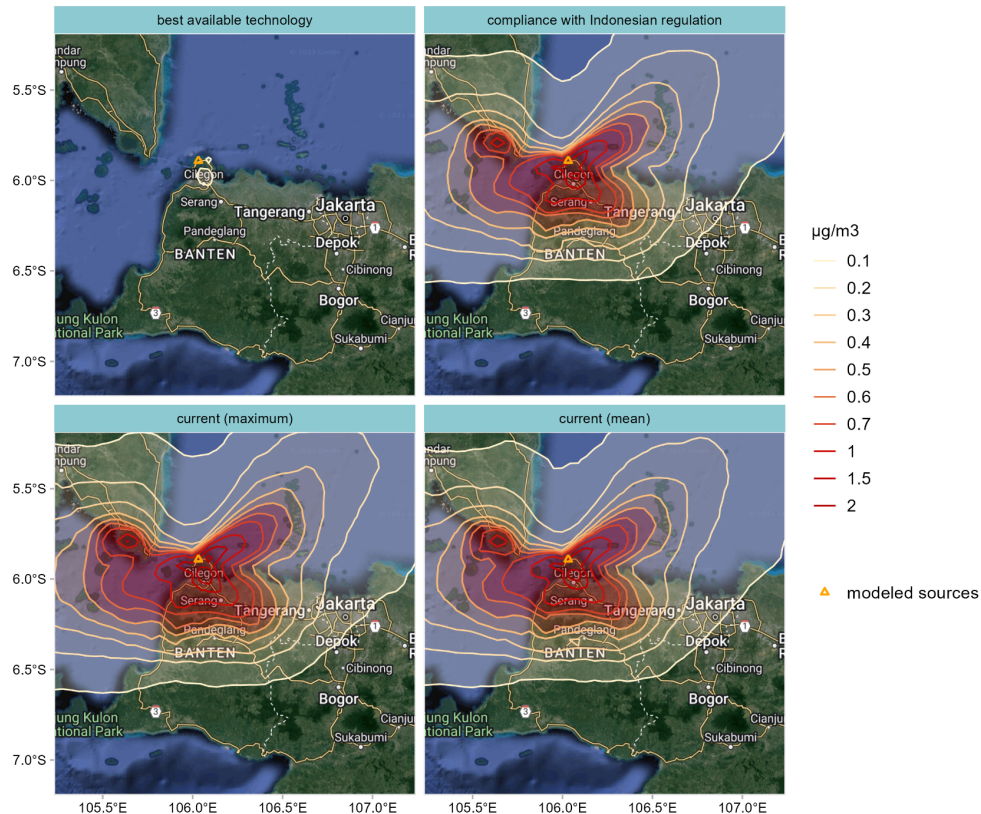
Source: CALPUFF (Exponent, 2015)

**Figure A1. Annual mean NO<sub>2</sub> from the Banten-Suralaya complex**

Note: Simulated under three different emission scenarios (Base - top; Compliance - middle; BAT - bottom).

### Annual mean SO<sub>2</sub> concentration from Banten Suralaya complex

by scenario



CREA

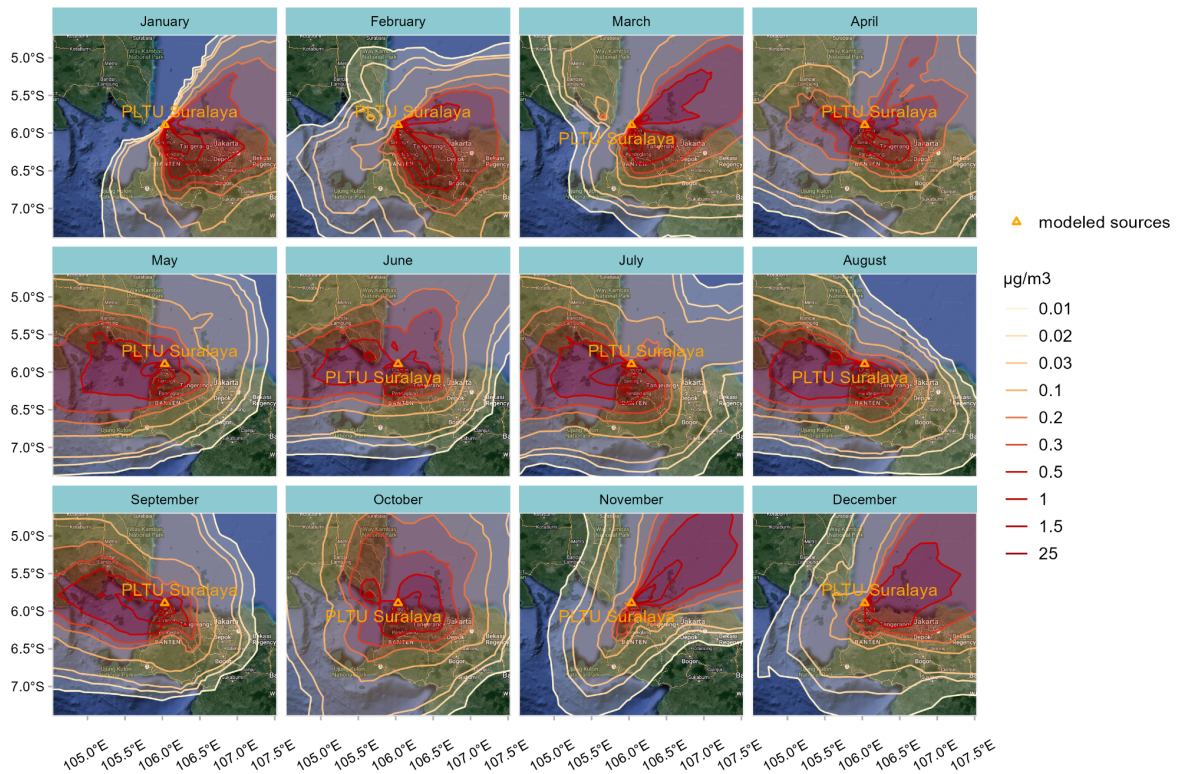
Source: CALPUFF (Exponent, 2015)

**Figure A2. Annual mean SO<sub>2</sub> from the Banten-Suralaya complex**

Note: Simulated under three different emission scenarios (Base - top; Compliance - middle; BAT - bottom).

### NO<sub>2</sub> concentration from Banten-Suralaya coal power plant

average by month



Source: CALPUFF (Exponent, 2015)

**Figure A3. Monthly mean NO<sub>2</sub> from the Banten-Suralaya complex**

**Table A1. Impacts of air pollution from the Banten-Suralaya complex on annual mortality (deaths per year)**

Pollutant	Base	Bsae_Max	Compliance	BAT
PM <sub>2.5</sub> + NO <sub>2</sub> + SO <sub>2</sub>	1,470 (920 – 2,270)	1,640 (1,020 – 2,570)	1,370 (853 – 2,140)	113 (72 – 169)
PM <sub>2.5</sub>	989 (681 – 1,330)	1,080 (742 – 1,450)	911 (628 – 1,230)	82 (57 – 110)
NO <sub>2</sub>	314 (135 – 701)	383 (165 – 854)	309 (133 – 689)	18 (8 – 39)
SO <sub>2</sub>	167 (100 – 243)	182 (109 – 266)	153 (92 – 224)	13 (8 – 19)

Source: CALPUFF model (Exponent, 2015) and in health impact assessment (Myllyvirta, 2020).

**Table A2. Impacts of air pollution from the Banten-Suralaya complex on annual morbidity health outcomes**

Health Outcome	Base	Base_Max	Compliance	BAT
Asthma emergency room visits	1,790 (1,070 – 2,500)	1,940 (1,160 – 2,720)	1,640 (981 – 2,300)	148 (88 – 207)
New cases of asthma in children	1,010 (230 – 2,190)	1,220 (281 – 2,670)	988 (227 – 2,160)	56 (13 – 122)
Preterm births	936 (454 – 993)	1,020 (494 – 1,080)	862 (418 – 915)	78 (38 – 83)
Low birthweight births	612 (190 – 1,060)	666 (207 – 1,160)	564 (175 – 978)	51 (16 – 88)

Work absence (thousand sick leave days)	742 (631 – 852)	808 (688 – 928)	684 (582 – 785)	62 (52 – 71)
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Source: CALPUFF model (Exponent, 2015) and in health impact assessment (Myllyvirta, 2020).

**Table A3. Annual health-related economic damages of air pollution from the Banten-Suralaya complex**

Currency	Base	Base (max)	Compliance	BAT
USD billion	1.04 (0.65 – 1.60)	1.16 (0.72 – 1.80)	0.97 (0.6 – 1.50)	0.08 (0.05 – 0.12)
IDR trillion	14.2 (8.8 – 21.8)	15.8 (9.7 – 24.5)	13.2 (8.2 – 20.4)	1.1 (0.7 – 1.6)

Source: CALPUFF model (Exponent, 2015) and in health impact assessment (Myllyvirta, 2020).