DOUBLE STANDARD

이중기준

A DEADLY DOUBLE STANDARD

South Korea's Financing of Highly Polluting Overseas Coal Plants Endangers Public Health

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Contents

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Executive summary

South Korea is the third biggest public investor in overseas coal-fired power plant projects among the G20 countries through its public finance agencies (PFAs); Korea Trade Insurance Corporation (K-SURE), Export-Import Bank of Korea (KEXIM) and Korea Development Bank (KDB). Coal is the single worst contributor to global climate change, responsible for almost half the world's carbon dioxide emissions.[1, 2] In addition, burning coal releases high amounts of dangerous air pollutants that are known to be responsible for premature deaths by causing and worsening a range of severe diseases.[3, 4] Most overseas coal power projects financed by South Korea employ air pollution emission control technologies far inferior to those required at home. In effect, South Korea is operating a deadly double standard: Financing coal-fired power plants overseas that create air pollution at levels that would not be legal in South Korea. **This study evaluated ten such plants, estimating that 1,600 to 5,000 premature deaths will be caused each year, amounting to between 47,000 to 151,000 total premature deaths over the typical 30-year operation period of such power plants.**

The double standard in emission limits for dangerous air pollutants allows South Korean-financed coal power plants overseas to emit up to 18.6 times more nitrogen oxides (NO_x), 11.5 times more sulfur dioxide (SO_2) and 33 times more dust pollution than those built in South Korea. This report reveals the deadly consequences of that double standard, in terms of premature deaths projected to be caused by air pollution based on modeling, and evaluates how many of those anticipated premature deaths could be avoided if the projects funded (either fully or jointly) by South Korea overseas applied the same emission limits as the new coal power plants in South Korea.

The impact of South Korea's double standard in emission limits is evaluated by comparing the number of premature deaths caused in two different scenarios:

- **Scenario 1:** Predicted coal-fired power plant emissions based on the application of current local emission limits and actual or projected plant utilization.
- **Scenario 2:** Predicted coal-fired power plant emissions if South Korean emission standards for new coal power plants (installed since January 2015) were applied.

In South Korea, public concern about air pollution and strong demands for clean air mean that the emission standards set in South Korea's Clean Air Conservation Act (2019) for new power plant projects are strict.[5] We carried out detailed atmospheric modeling and health impact assessments for 10 coal power plants that are located near populated areas and were financed by South Korean PFAs overseas during the period of January 2013 to August 2019. These coal power plants are located in Bangladesh, Indonesia and Vietnam.

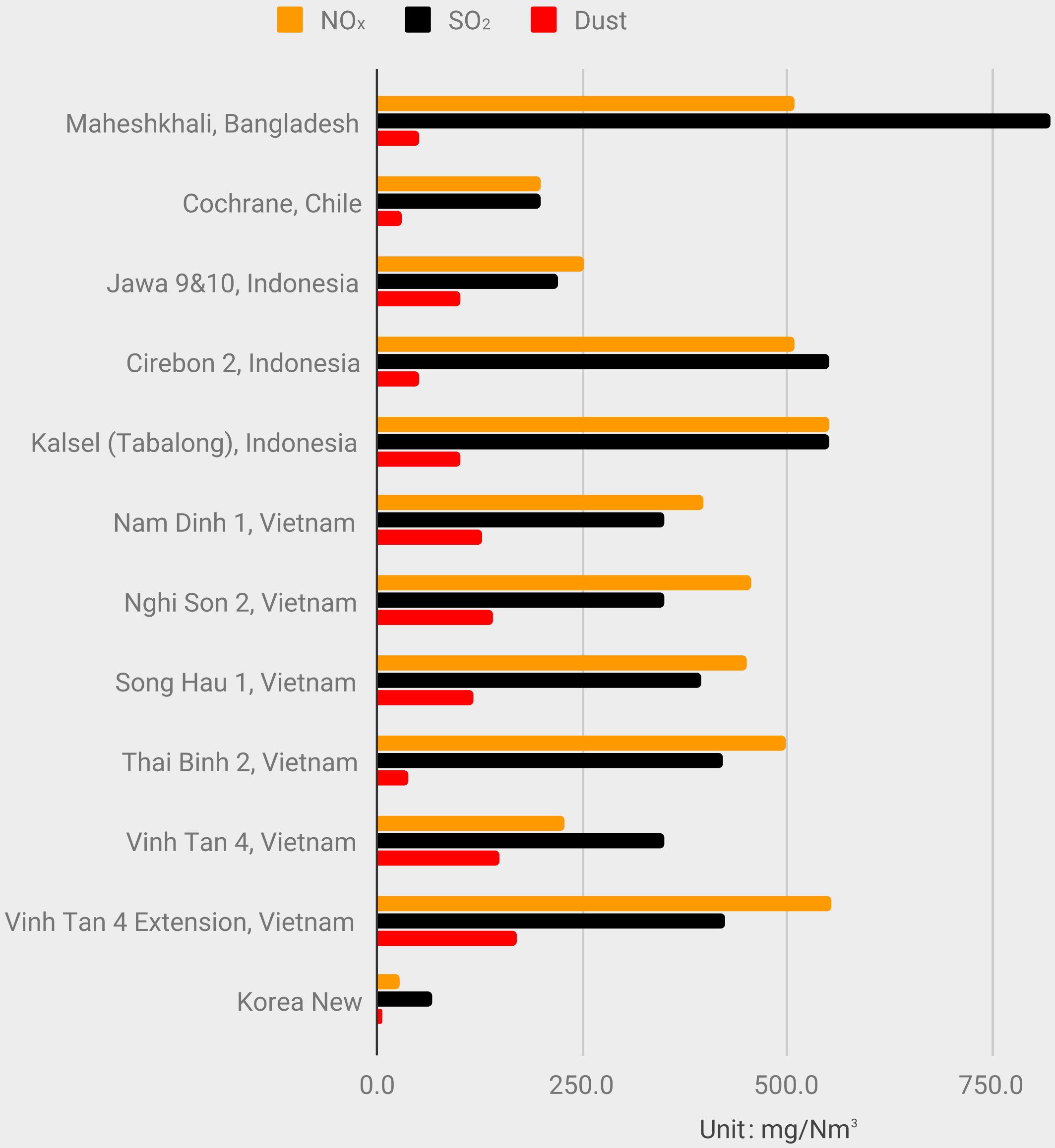

Figure: Emission standards for air pollutants NO_x, SO_2 and Dust for South Korean coal power plants[6] compared to emission limits of South Korean PFA-financed coal power plants in other countries[7].

Our results indicate that if the South Korean emission standards were applied – not just in South Korea but to all coal power plants financed by South Korean PFAs outside of South Korea – an estimated 1,400 to 4,500 premature deaths would be avoided each year. Over the typical 30-year operation period of such power plants, this amounts to between 42,000 and 136,000 avoidable premature deaths projected to result from the 10 coal power plants financed by South Korean PFAs and operating with poor emission limits.

Most of the premature deaths are projected to occur in the host countries themselves. These countries have existing dangerous air pollution problems separate to the pollution that would be caused by the modeled coal power plants. South Korean investments in coal power will only make it harder for these countries to reduce air pollution and meet public health standards.

Air pollution generated by the modeled power plants was shown to disperse across national borders. As a result, 13% of the projected premature deaths occur in seven neighboring countries which are otherwise uninvolved in the power plant projects.

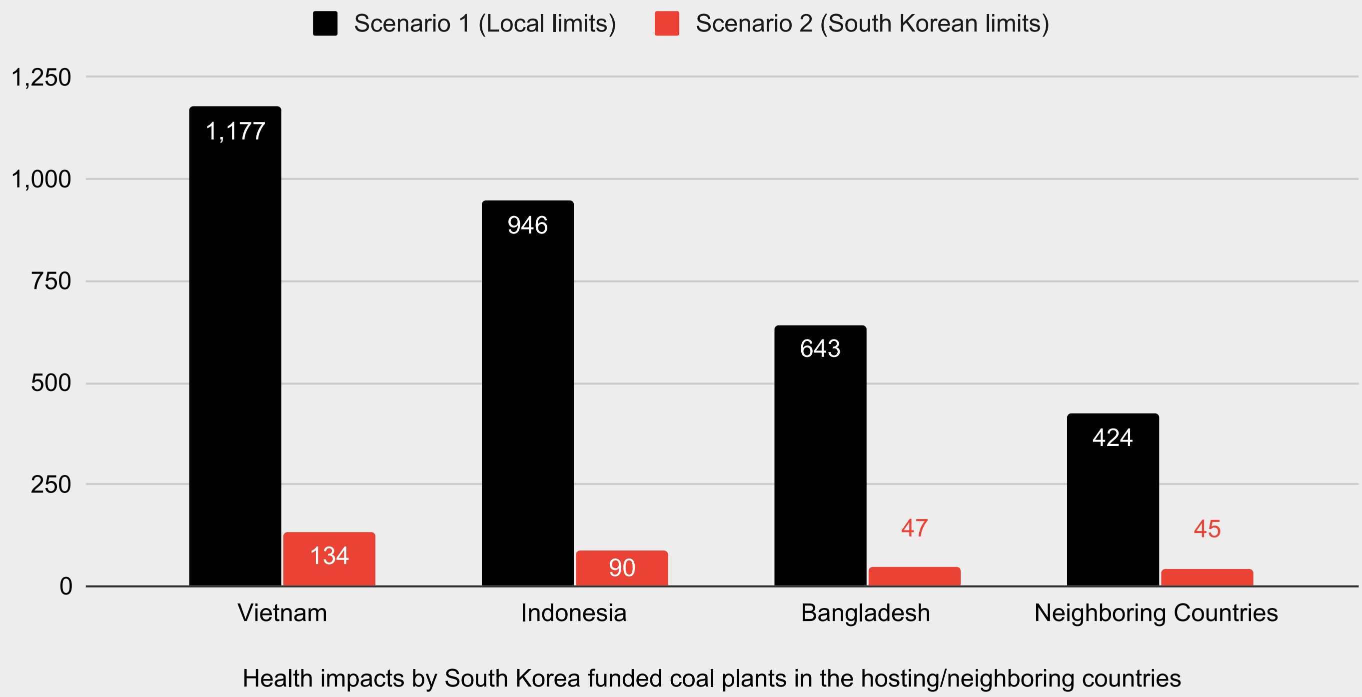

Figure: Projected number of premature deaths per year in the hosting and neighboring countries due to South Korean PFA-financed coal power plants operated under local emission limits (black) vs. operated in line with South Korean emission standards(red). Uncertainty range is about 50% (exact values are shown in the result section).

All countries need to shift immediately away from coal and toward renewable energy sources to avoid catastrophic climate change and prevent the health impacts of coal emissions, including premature death. Countries must work together towards a carbon-neutral economy, and South Korea should play a leadership role in doing so. In contrast to the unethical and deadly double standard that South Korea is applying now to coal power projects – which is linked to illnesses, premature deaths and climate change – South Korea's PFAs should instead support renewable energy solutions. Renewable energy and energy efficiency are getting cheaper and competitive[8] than building new coal-fired power plants, and rather than exacerbating air pollution and climate change, they provide a solution.

The South Korean Government has announced an energy transition plan with a target for 20% renewable energy by 2030, together with a nuclear phase out plan and an end to permits for new coal projects.
In addition, the Government is renewing regulations on air pollution emissions of coal plants every year. Despite this, South Korea's public finance agencies (PFAs) still invest heavily in coal-fired power plants in other countries.
The South Korean Government must take urgent action to end this financing and ensure its PFAs move to fund renewable solutions rather than coal.

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Figure: Locations of South Korean PFA-financed coal power projects overseas, from January 2013 to August 2019.

Additionally, the South Korean Government must immediately stop its PFAs from investing in overseas projects in the power, industrial and other sectors if their emission limits do not meet the standards applied in South Korea. By ending this deadly double standard, hundreds of thousands of lives could be saved.

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At the same time, the governments in the host countries of these coal projects should protect their citizens' right to a safe and healthy environment, by significantly strengthening their emission limits for existing coal power plants, while undertaking energy transition from coal to renewable energy in their countries. This change in policies and investments must be accelerated now, for human and environmental health, and to safeguard the future of our planet.

1. Introduction

Air pollution is estimated to cause over 7 million premature deaths across the world each year and is responsible for many non-communicable diseases globally.[9] According to calculations by the World Bank, premature deaths from air pollution cost the world's economy nearly 225 billion USD in 2013 in lost labor income alone.[10] While air pollutants arise from various sources, fossil fuels are a major contributor, and burning coal for power generation is one of the biggest contributors to air pollution globally.[11] Air pollution from coal plants is a significant issue for many countries in Southeast Asia, where it is projected to cause 70,000 premature deaths annually by 2030.[12]

Coal-fired power plants (CFPPs) emit pollutants including SO_2, NO_x and particulate matter (PM) into the air. This exposes people to toxic air pollution. The impacts of air pollution on public health are often not sufficiently considered by financiers of coal-fired power plants. Such investments are often promoted as serving development needs, without showing the full picture.

Global coal demand increased by 0.7% in 2018 after a brief decline between 2013 and 2016. This recent increase is due to higher demand in Asia, which has outpaced declines in other parts of the world.[13] According to the International Energy Agency (IEA), after China and India, Southeast Asia is one of the key regions where the demand for coal is growing.

According to the IEA, coal consumption in Southeast Asia increased substantially in Indonesia and Vietnam in 2018. Increasing electricity demand and a heavy reliance on coal for electric power generation in these countries has resulted in their coal-fired power generation increasing faster than their overall growth in power generation.[14]

An increase in coal power generation poses a risk to health by degrading air quality. Air quality in Bangladesh, Vietnam and Indonesia already ranks as some of the most unhealthy in the world. The construction of new coal plants will further increase pollution in these areas, and make it more difficult and expensive to reach acceptable ambient air quality standards.[15]

In addition to contributing to the problem of air pollution, coal-fired power is the single worst contributor to global climate change. Many nations are working to phase out coal in order to meet their commitments under the Paris Agreement[16] to keep global temperature rise within 1.5°C to 2°C.

Countries in the Organization for Economic Cooperation and Development (OECD) must phase out coal by 2030, and the rest of the world by 2050, to avert the worst consequences of climate change.[17] However, while many countries move to phase out coal, others are both financing and building coal-fired power plants, even in countries that are highly vulnerable to extreme weather and climate change.

Air pollution is estimated to cause over 7 million premature deaths across the world each year and is responsible for many non-communicable diseases globally.

This report analyzes how South Korea, the third biggest public investor in overseas coal-fired power plant projects among the G20 countries, is set to continue funding dirty coal.

Public finance agencies (PFAs) from China, South Korea and Japan are accountable for most of the public financing of overseas coal power.[18] These three countries alone have financed, or committed to finance, coal power with 53 billion USD of loans and other public financing between 2013 and 2018. This is close to 88% of the total overseas coal financing of all G20 countries.[19,20,21]

This report analyzes how South Korea, the third biggest public investor in overseas coal-fired power plant projects among the G20 countries, is set to continue funding dirty coal. This reckless investment would impact upon millions of lives by contributing to devastating regional health impacts from polluted air, and the acceleration of global climate change.

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Coal power projects funded by South Korea's public finance agencies

South Korea is among the world's top financiers of overseas coal projects through public investments.

Between January 2013 and August 2019, financing[22] of overseas coal-fired power plants by South Korea's PFAs amounted to 5.7 billion USD, for a capacity of 7 gigawatts (GW), and 4.5 GW of new coal plants are under review for possible investment. The majority of public financing by South Korea during this period was in South and Southeast Asia, particularly Vietnam (72%), Indonesia (22%) as well as in Chile (6%) (Figure 1).

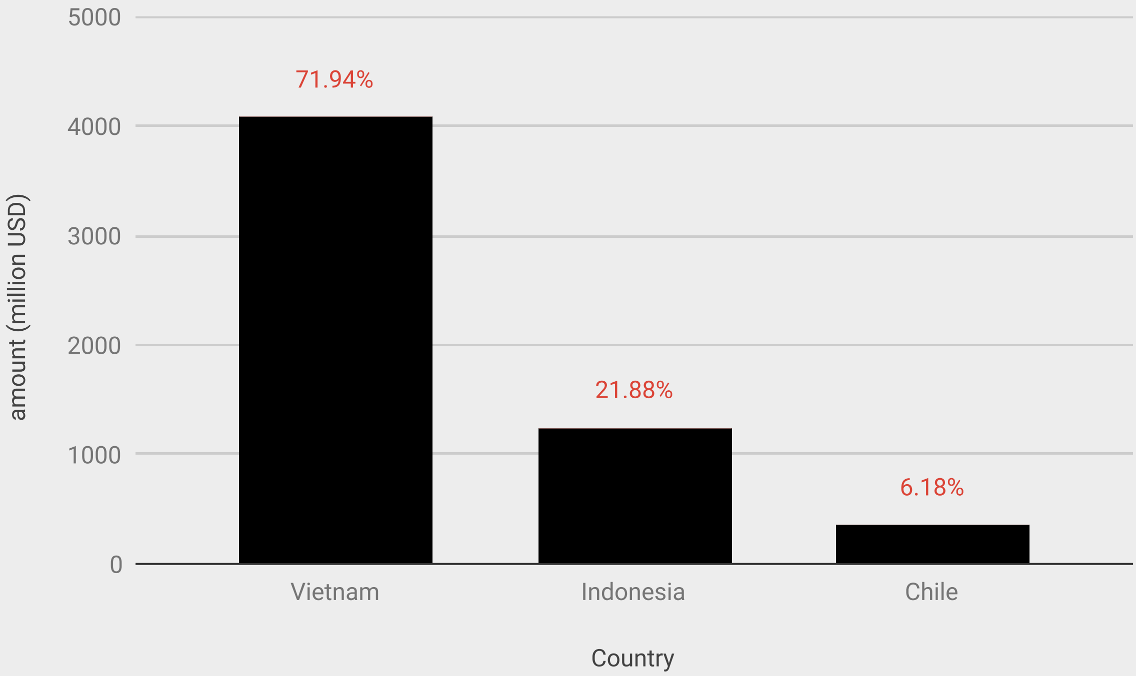

Figure 1. South Korean public finance agencies' overseas coal financing by country (Jan 2013 - Aug 2019).[23,24]

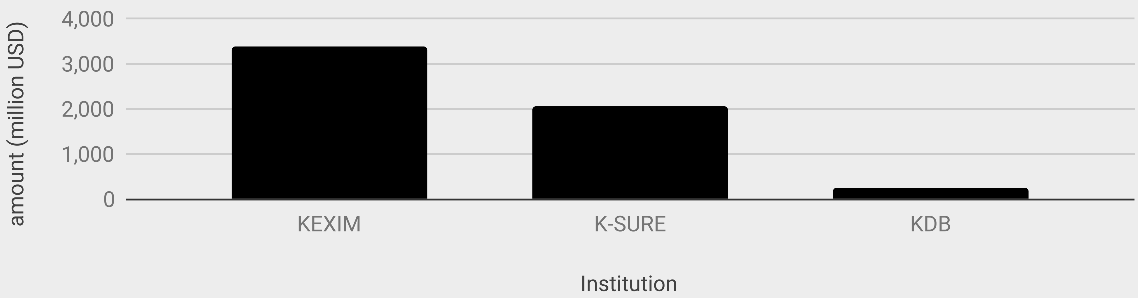

Figure 2. South Korean public finance agencies' overseas coal financing by institution (Jan 2013 - Aug 2019).

Table 1.
South Korean public finance agencies' funding for overseas coal power projects (Jan 2013 - Aug 2019).

Institution	Host Country	Project Name	Capacity (MW)[25]	Amount (USD)	Year of Financial Close
KEXIM	Bangladesh	Maheshkhali Coal Plant KEPCO	1,320	TBD	Future
K-SURE	Chile	Cochrane Coal-Fired Power Project	472	250,000,000	2013
KEXIM				100,000,000	2013
KEXIM	Indonesia	Jawa Power Plant units 9&10[26]	2,000	TBD	Future
K-SURE				TBD	Future
KEXIM	Indonesia	Cirebon Coal Plant Phase 2	1,000	522,000,000	2017
K-SURE	Indonesia	KalSel (Tabalong) Coal-Fired Power Plant	200	485,000,000	2016
KDB				232,000,000	2017
KEXIM	Vietnam	Nam Dinh I Coal Plant	1,200	TBD	Future
KEXIM	Vietnam	Nghi Son 2 Coal Plant	1,200	936,000,000	2018
K-SURE	Vietnam	Song Hau 1 Power Plant	1,200	507,000,000	2016
KEXIM				480,000,000	2016
KEXIM	Vietnam	Thai Binh 2 Coal Power Plant	1,200	600,000,000	2013
K-SURE	Vietnam	Vinh Tan 4 Coal-Fired Thermal Power Plant	1,200	455,000,000	2014
KEXIM				455,000,000	2014
K-SURE	Vietnam	Vinh Tan 4 Coal-Fired Power Plant Expansion	600	341,000,000	2017
KEXIM				300,000,000	2017
Total			**11,592**	**5,663,000,000**	

The South Korean PFA-funded projects list is based on NRDC's consolidated coal finance database and list of coal power investments by KEXIM, K-SURE, KDB (highlighting indicates future projects).


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2. South Korea's contradictory policies on coal

In 2017, in the 8th Basic Plan for Electricity Supply and Demand (8th BPE), the South Korean Government committed not to allow further new coal power projects domestically and to gradually reduce coal power.[27] Additionally, to reduce air pollution, the government revised the Clean Air Conservation Act in May 2019 to impose stricter emissions standards for all facilities including thermal power plants and industries.[28] Recently the government has been examining if it should adopt a policy to temporarily shut down 9 to 27 coal plants and to limit the operation of other coal plants from December to March every year, in the heavy air pollution season.[29]

Local governments in South Korea are also taking progressive steps towards a coal phase out. Chungnam province, which has close to half of the coal-fired power plants in South Korea, is the first member of the Powering Past Coal Alliance (PPCA) in the East Asia region to have a 2050 coal phase out target. It is also asking the central government to shut down existing coal power plants earlier than the end of their current lifespan.[30]

Under the Nationally Determined Contributions (NDC) target in the Paris Agreement,[31] South Korea has committed to a 37% reduction in greenhouse gas (GHG) emissions from its Business-As-Usual (BAU) scenario by 2030.[32] Additionally, South Korea also hosted the 48th session of the Intergovernmental Panel on Climate Change (IPCC) to support the adoption of the Special Report on Global Warming of 1.5°C[33] in October 2018. In the congratulatory address, President Moon Jae-in pledged South Korea's commitment towards climate action to keep temperature rise below 1.5°C.[34]

Recently at the UN Climate Action Summit, President Moon Jae-in announced that South Korea would host the Partnering for Green Growth and the Global Goals 2030 (P4G) Summit in 2020, and accelerate the country's efforts to fight climate change. He proposed the designation of an "International Day for Blue Sky" calling for international cooperation to address air pollution, and in doing so mentioned that severe air pollution causes more than 7 million premature deaths globally each year.[35]

"In order to improve air quality, cross-border international cooperation and joint responses are definitely required, including joint research and technological support. The Republic of Korea is bolstering cooperation with the international community by establishing the National Council on Climate and Air Quality chaired by former UN Secretary-General Ban Ki-moon. The international community's joint efforts to improve air quality are a way to usher in a low-carbon era. I call for participation and support from member states."

- President Moon, Jae-in, at the United Nations Climate Action Summit in New York, 23 Sep 2019.

Recently, the South Korean Government has put considerable effort towards building strong cooperation with the Association of Southeast Asian Nations (ASEAN) countries through its New Southern Policy, which is promising to support ASEAN countries with infrastructure and economic development. Clean energy and the technological support for climate change response and mitigation are among the issues on which ASEAN countries expect assistance from South Korea.[36] The 2019 ASEAN-ROK Commemorative Summit which will be held on 25th November 2019 in Busan, South Korea, will discuss a "Partnership for Peace, Prosperity for People".

In light of these promises and announcements, South Korea's continued financing of overseas coal power plant projects, the major source of air pollution and global carbon dioxide emissions[37,38] is contradictory and hypocritical.

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3. A deadly double standard: Financing air pollution

South Korea's financing of overseas coal projects through PFAs contrasts with its emerging, though still limited, steps away from coal power at home. A particularly clear divide can be seen in South Korea's attitude to combating air pollutant emissions from coal power generation. Domestically, South Korea is aiming to reduce coal power in the energy mix, and is applying relatively strong emission standards on new coal plants to reduce air pollution within the country. However, South Korean PFA-funded coal projects overseas are applying emission limits for air pollutants that are orders of magnitude poorer than would be required within South Korea.

South Korea's public financing of overseas coal power projects normally (but not always) follows the Coal-Fired Electricity Generation Sector Understanding (CFSU) under the OECD Arrangement on Officially Supported Export Credits. The CFSU limits support to coal plants utilizing ultra-supercritical (USC) technology; or in the case of the poorest countries, supercritical (SC) or subcritical (SUBC) plants smaller than 500MW or 300MW of capacity respectively.[39]

Regardless, even high efficiency coal plants using ultra-supercritical technology are major sources of air pollutants, and the gains in efficiency from ultra-supercritical technology are far from enough to protect public health.[40] This will be described further in chapter four of this report.

A deadly Double standard in Emission limits for coal power plants

Coal-fired power plants emit a multitude of dangerous substances, among them:

- **Nitrogen dioxide (NO_2):** A gas that is produced in all combustion processes. It converts from and to nitrogen monoxide (NO). The amount of NO_2 in the atmosphere is commonly used as a proxy to assess the health impact of the whole NO_x group (i. e. NO and NO_2).
- **Sulfur dioxide (SO_2):** A gas produced by industrial processing of materials that contain sulfur, including coal burning in power plants and processing of some mineral ores. About 99% of the sulfur dioxide in the air comes from human sources. SO_2 reacts with other substances to form harmful compounds, such as sulfuric acid (H_2SO_4), sulfurous acid (H_2SO_3) and sulfate particles and it is therefore a cause of acid rain and particulate matter pollution.
- **Fine particulate matter ($PM_{2.5}$):** Solid particles with aerodynamic diameter of less than 2.5µm (i. e. small dust particles).[41] These are so small that they can pass from the lungs into the bloodstream, affecting the entire cardiovascular system and causing a range of health impacts. Due to their small size, the particles stay airborne for a long time and can travel hundreds or thousands of kilometers. Fossil fuel combustion emits $PM_{2.5}$ directly, as fly ash and other unburned particles, and contributes to $PM_{2.5}$ indirectly through emissions of gaseous pollutants (particularly SO_2 and NO_x) which form $PM_{2.5}$ in the atmosphere.

Through its PFA financing of highly polluting coal power plants overseas, South Korea is effectively exporting pollution which is projected to cause illness, premature deaths, environmental degradation and climate change.

South Korea applies stringent emission standards to its domestic coal-fired power plants. The emission standards for new coal plants over 100 MW capacity, installed after January 2015, are 28, 65 and 5 mg/Nm^3 for NO_x, SO_2 and dust respectively.[42] Moreover, the most recently constructed coal plants are applying much stricter emission limits. For example, Gangneung ECO power is applying emission limits of 19, 39 and 3 mg/Nm^3 for NO_x, SO_2 and dust respectively for a 1,000 MW capacity new coal-fired power plant currently under construction.[43]

In contrast, South Korea's PFAs are supporting overseas coal power plant projects applying far more lenient air pollution emission limits than domestic coal power plants. We present here an analysis of the environmental and human health impacts of overseas coal-fired power plant projects financed by South Korea's PFAs.

A comparison of the discrepancies between overseas emission limits and the emission standards for South Korea's domestic coal power plants is shown in Figures 3-5 and Table 2. For example, compared to South Korean standards, the Maheshkhali coal-fired power plant project in Bangladesh, which KEXIM is currently considering supporting, is allowed to emit almost 17 times more air pollution, with emission limits of 510, 820 and 50 mg/Nm^3 for NO_x, SO_2 and dust, respectively. Emission limits of the Nghi Son-2 plant in Vietnam, which KEXIM decided to financially support in 2018 are 455, 350 and 140 mg/Nm^3 for NO_x, SO_2 and dust, respectively 15 times poorer for NO_x, 4 times poorer for SO_2 and 27 times poorer for dust than South Korea's domestic standards. Across all the plants assessed in this study, the greatest discrepancies are; 19 times more nitrogen oxides (NO_x) (Vinh Tan 4, Vietnam), 12 times more sulfur dioxide (SO_2) (Maheshkhali, Bangladesh) and 33 times more dust pollution (Vinh Tan 4, Vietnam) when compared to South Korean standards.

Emissions from coal power plants elevate the levels of particulate matter and gaseous pollutants in the air over a large area spanning hundreds of kilometers, putting populations downwind of the power plants at risk and impeding the ability of cities and regions to protect public health or meet their air quality standards. In some locations, even a 1 µg/m^3 increase in $PM_{2.5}$ concentration could cause an exceedance of air quality standards when combined with pollution from other sources. This may require costly mitigation measures to be put in place by the affected jurisdiction. This pollution increases the risk of diseases such as stroke, lung cancer, heart and respiratory illness in adults, as well as respiratory infections in children.[44]

Air pollution increases the risk of diseases such as stroke, lung cancer, heart and respiratory illness in adults, as well as respiratory infections in children.

These air pollution impacts are expected to lead to premature deaths in the affected populations. In addition, emissions from coal plants cause acid rain, which can damage or destroy forests, crops, soils, waterways and wildlife as well as fallout of toxic heavy metals such as arsenic, nickel, chrome, lead and mercury.

Although countries are primarily responsible for regulating air pollution from coal power plants through their own national emission standards, South Korea shares responsibility for the coal plants it finances in countries with poor emission standards, and must align those projects with its domestic emission standards. South Korea has developed technology to reduce emissions, and there is no excuse for allowing lower standards in PFA-financed coal power projects overseas.

The current differences in emission standards and thus in levels of air pollution and impacts represent an unethical and deadly double standard. As a political and economic leader within the G20 and among OECD countries, South Korea must be consistent and apply the same standards to both domestic and overseas projects.

Not only does this deadly double standard impact upon the health of people and the environment in recipient countries, it also damages South Korea's reputation. Through its PFA financing of highly polluting coal power plants overseas, South Korea is effectively exporting pollution which is projected to cause illness, premature deaths, environmental degradation and climate change.

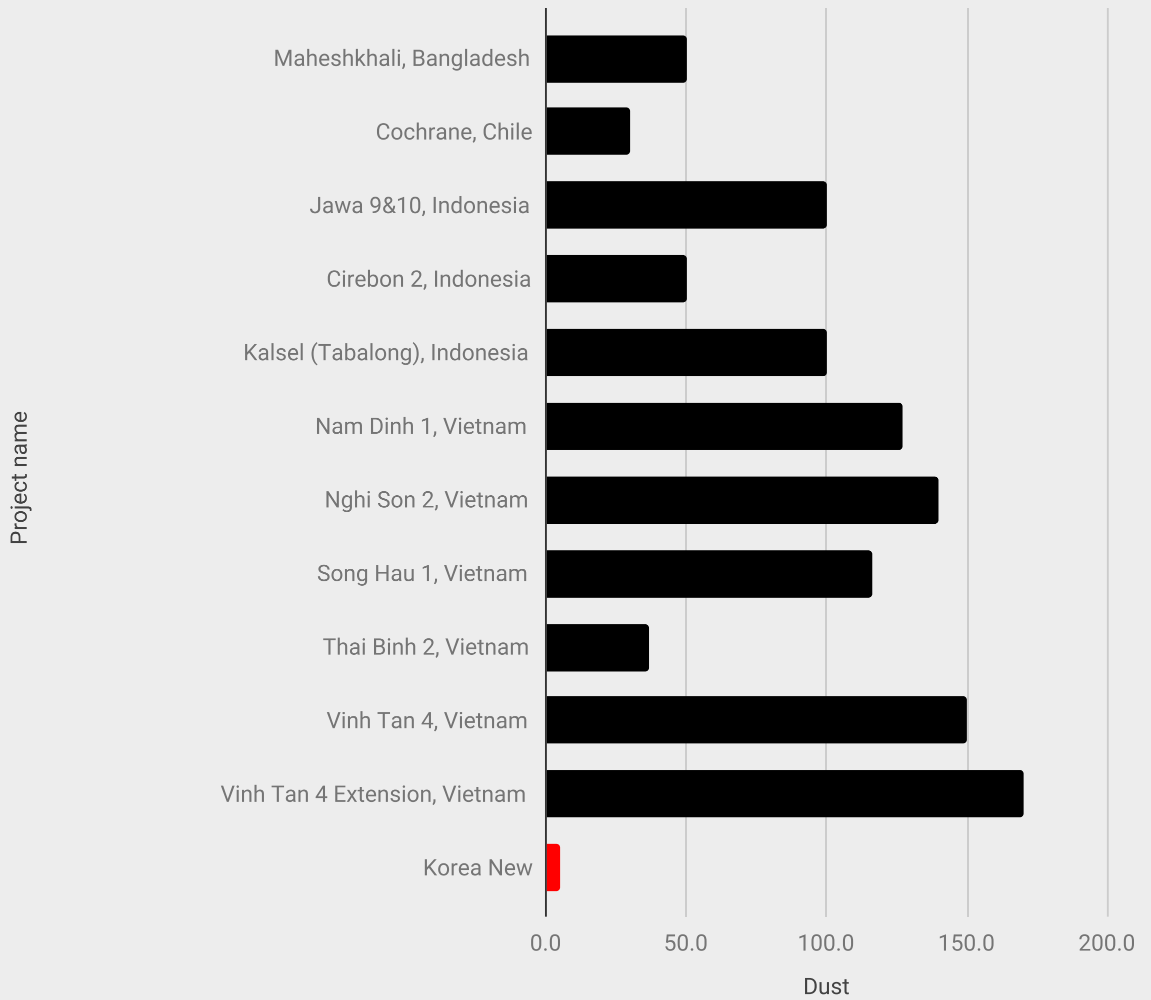

Figure 3. Emission limits for dust: South Korean emission standards for new coal plants[45] vs. emission limits of overseas projects with South Korean financing (mg/Nm^3).

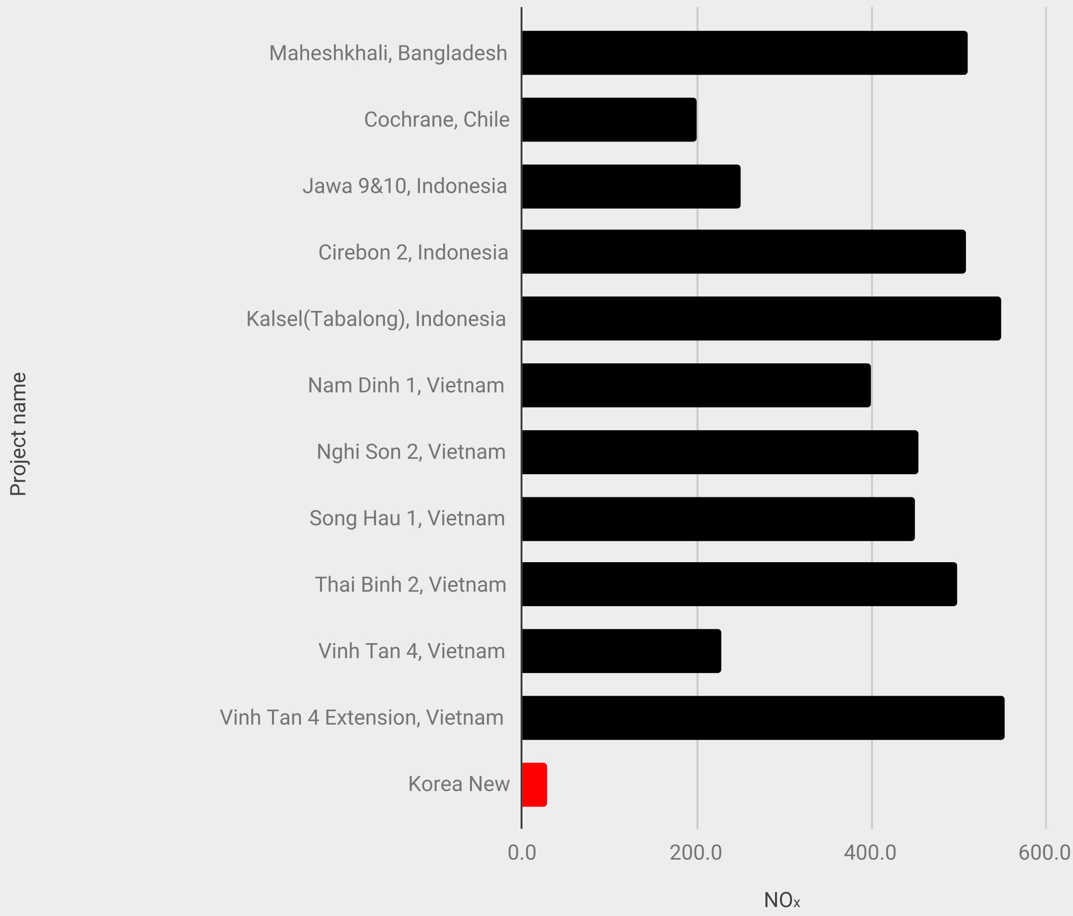

Figure 4. Emission limits for NO_x: South Korean emission standards for new coal plants[46] vs. overseas projects with South Korean financing (mg/Nm³).

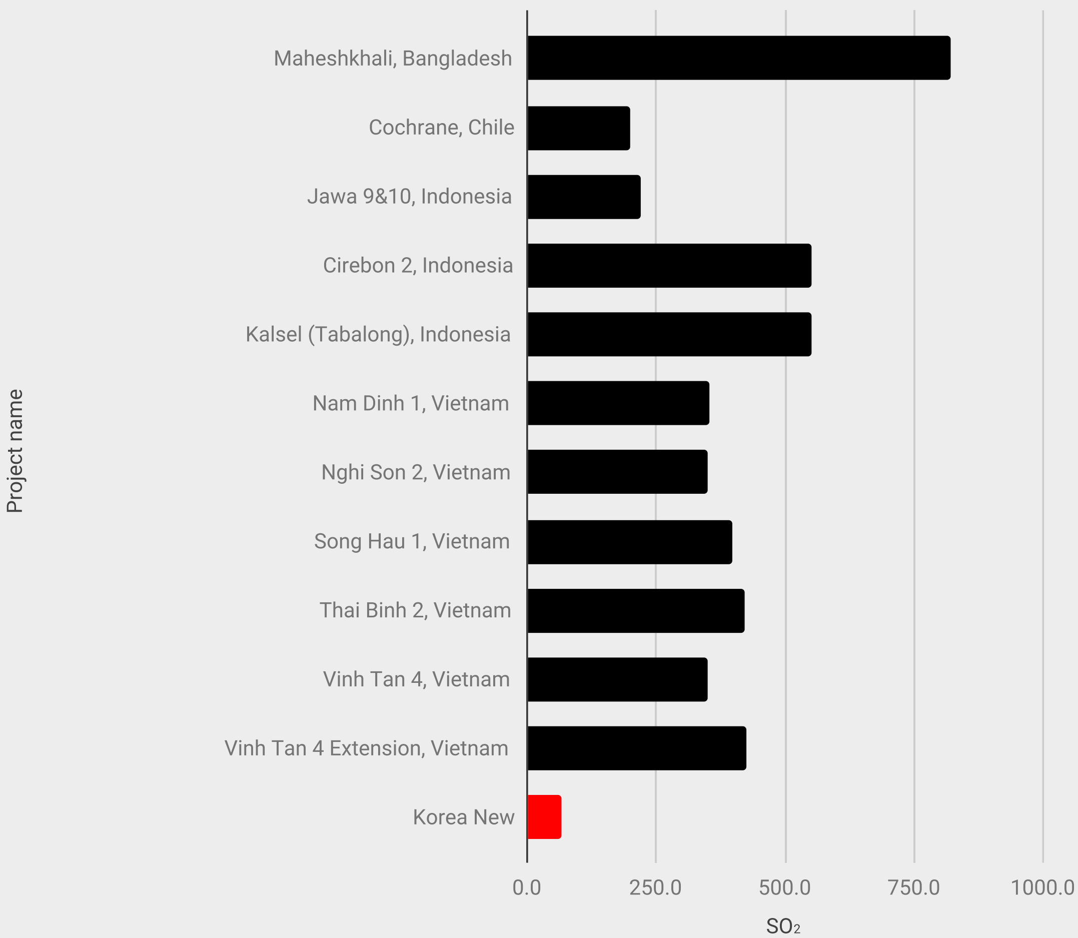

Figure 5. Emission limit for SO_2: South Korean emission standards for new coal plants[47] vs. emission limits of overseas projects with South Korean financing (mg/Nm³).

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Table 2. Emission limits on coal power plants:
South Korea domestic vs recipient countries

Country	Project name	Emission limit(mg/Nm^3)			Boiler efficiency
		NO_x	SO_2	Dust	
South Korea	Emission standards for new coal plants	28	65	5	USC
Bangladesh	Maheshkhali Coal Plant	510	820	50	USC
Chile	Cochrane Coal-Fired Power Project	200	200	30	SUBC
Indonesia	Jawa Power Plant units 9&10	251	221	100	USC
Indonesia	Cirebon Unit 2	509	550**	50	USC
Indonesia	Kalsel (Tabalong) power station	550	550*	100*	SUBC
Vietnam	Nam Dinh-1	399	351	127	SC
Vietnam	Nghi Son-2	455	350	140	SC
Vietnam	Song Hau-1	450	396	116	SC
Vietnam	Thai Binh-2	500	422	37	SC
Vietnam	Vinh Tan-4 extension	553	425	170	USC
Vietnam	Vinh Tan-4	228	350	150	SC

- All data is extracted from the relevant project Environmental Impact Assessments (EIAs) and the Global Coal Plant Tracker[48] or obtained from the South Korean PFAs submitted data.
- USC (Ultra-supercritical) / SC (Supercritical) / SUBC (Subcritical)
* Emission limits for Kalsel (Tabalong) CFPP are not available, so figures are based on the newly enacted (23 April 2019) emission standards for coal power plants in Indonesia, which specify limits of 550 mg/Nm^3 each (for NO_x and SO_2) and 100 mg/Nm^3 (dust) for plants operating or constructed before the regulation was enacted.
** Based on the project EIA, the SO_2 emissions from Cirebon 2 CFPP exceeds the newly enacted emission standards. It can be assumed that this CFPP will follow the new standard.

Modeling the emissions and health impacts from this double standard

In order to quantitatively assess the impacts of South Korea's double standard on air quality and the resulting impacts on human health, the dispersion of air pollutants emitted by existing and proposed coal-fired power plants has been modeled. Emission data used in the modeling were extracted from each project's EIA and PFAs submitted data, or estimated based on publicly available data. This includes countries' national emission standards and Global Energy Monitor's global coal plant tracker database[49] where EIA data were not available. A detailed technical description of the model is provided in the Appendix.

The model simulation predicts near-surface pollutant concentrations over the course of one calendar year. It has been run for the 10 South Korean PFA-funded coal power plants that are located near populated areas in Bangladesh, Indonesia and Vietnam (Fig. 6).[50] In order to measure the impacts of the double standard, the model has been run for two different scenarios for each of these 10 different plants:

- **Scenario 1:** Predicted coal-fired power plant emissions based on actual emission limits and actual or projected plant utilization.
- **Scenario 2:** Predicted coal-fired power plant emissions if South Korean emission standards for new domestic coal power plants (≥100MW, installed since January 2015) were applied.

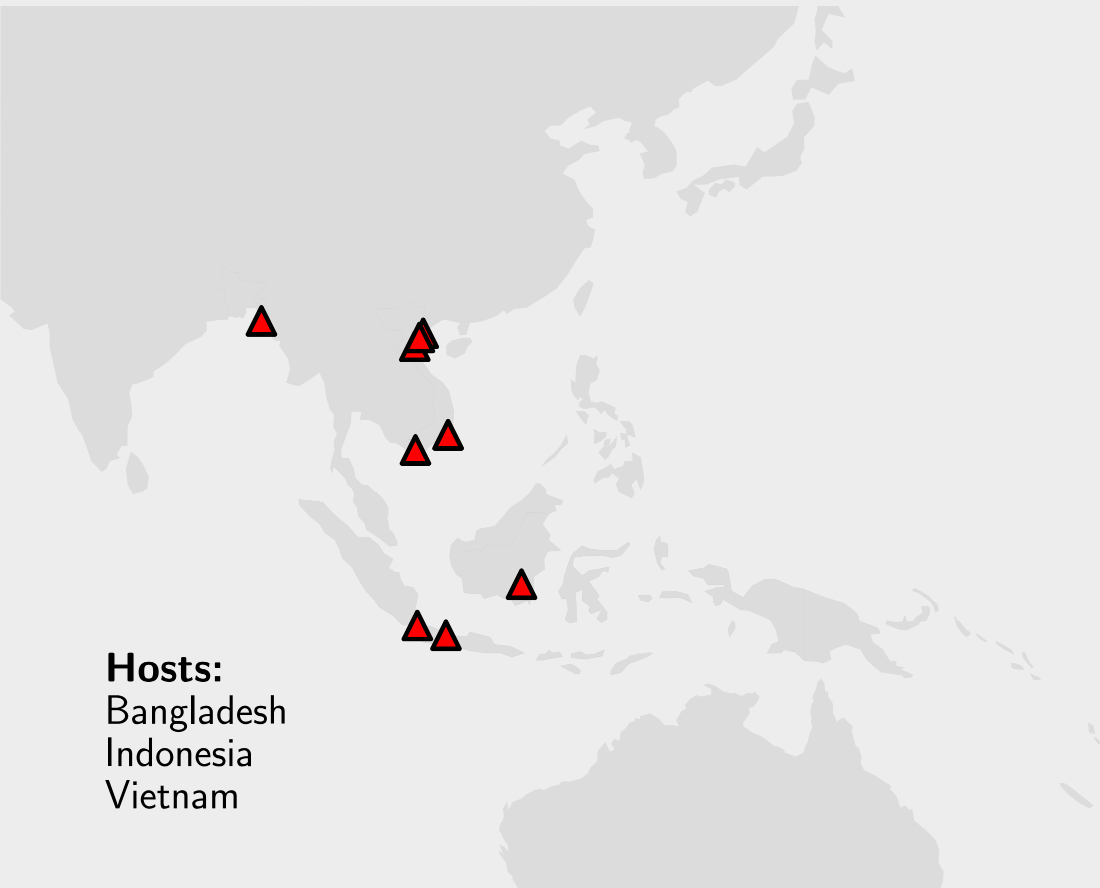


Figure 6. Locations of existing and planned coal-fired power plant projects financed by South Korean PFAs between January 2013 and August 2019 in foreign countries.

Pollutant concentrations

The World Health Organization (WHO) publishes and updates Air Quality Guidelines for air pollutant concentrations over different averaging intervals (Tab. 3). They are the upper limit beyond which air pollution has been shown to be unsafe.[51] However, these limits do not imply that pollution levels below these values are harmless:

> ***"[A]s research has not identified thresholds below which adverse effects do not occur, it must be stressed that [these] guideline values [...] cannot fully protect human health."***[52]

Table 3.
WHO Air Quality Guidelines for maximum pollutant concentration over different averaging intervals.

Pollutant	NO_2 (µg/m^3)		SO_2 (µg/m^3)		$PM_{2.5}$ (µg/m^3)	
Averaging interval	**annual**	**1 hour**	**24 hours**	**10 minutes**	**annual**	**24 hours**
Air Quality Guideline (µg/m^3)	40	200	20	500	10	25

Figures 7-9 show the projected pollutant concentrations for some of the modeled power plants. Pollution from the power plants spreads tens to hundreds of kilometers to densely populated areas. In each of the three host countries, major metropolitan areas are affected by pollution originating from at least one of the modeled power plants:[53]

- **Bangladesh:** Chittagong (population around 3 million), affected by the Maheshkhali CFPP (Fig. 7, top row)
- **Indonesia:** Jakarta (34 million) and Bandung (6 million), affected by Cirebon-2 and Jawa 9&10 (Fig. 8, top and middle rows, respectively)
- **Vietnam:**
    - Ho Chi Minh City (11 million), affected by the Song Hau-1 CFPP (Fig. 9, top row)
    - Hanoi (8 million) and Haiphong (1.2 million) affected by the Thai Binh and Thai Binh-2 CFPPs (Fig. 9, bottom row)

During certain meteorological conditions, pollutant concentrations can be much higher than the annual average. In Chittagong (Bangladesh), for example, the highest modeled 24-hour average concentration of $PM_{2.5}$ from the Maheshkhali power plant is about 50 times higher than the modeled annual average (Fig. 7, middle vs. top row).

When running the power plants at local emission limits (Scenario 1), WHO guidelines are projected to be breached by 8 of the 10 modeled power plants, located in all three host countries (Tab. 4), with concentrations reaching levels that are up to 22 times higher than the WHO guideline limit (Maheshkhali, 24-hour SO_2 concentration, see bottom row of Fig. 7). As a result, millions of people are expected to be exposed to harmful air pollution: 2 million people live in areas modeled to be affected by SO_2 guideline exceedances, over 700 thousand by NO_2 guideline exceedances and close to 100 thousand by $PM_{2.5}$ guideline exceedances (Fig. 10 and Tab. 5).

If South Korean emission standards were applied (Scenario 2), pollutant concentrations would be reduced substantially for all power plants (right column in Figs. 7-9 and Tab. 4). Pollutant levels under Scenario 2 would be:

- 9 to 28 times lower for NO_2,
- 3 to 13 times lower for SO_2,
- 4 to 14 times lower for $PM_{2.5}$.

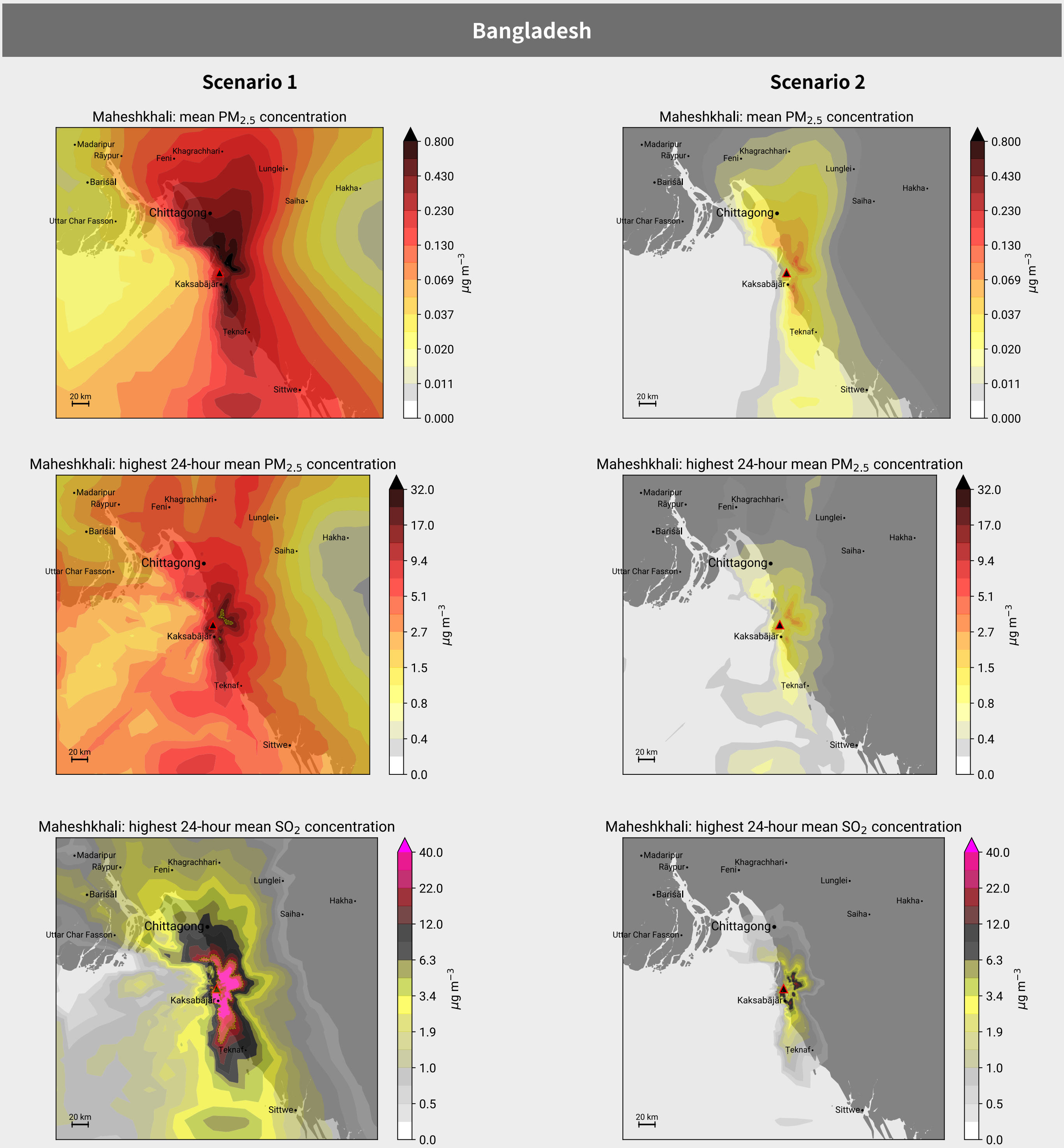


Figure 7. Modeled pollutant concentration from Maheshkhali power plant (triangle) in Bangladesh.
Left column: Scenario 1, right column: Scenario 2. Note that the color scales are logarithmic and different from one row to another.

With these reductions, the total number of people exposed to pollution levels exceeding WHO guidelines would decrease sharply by 99.8% from almost 2 million people to 4 thousand (Tab. 5).

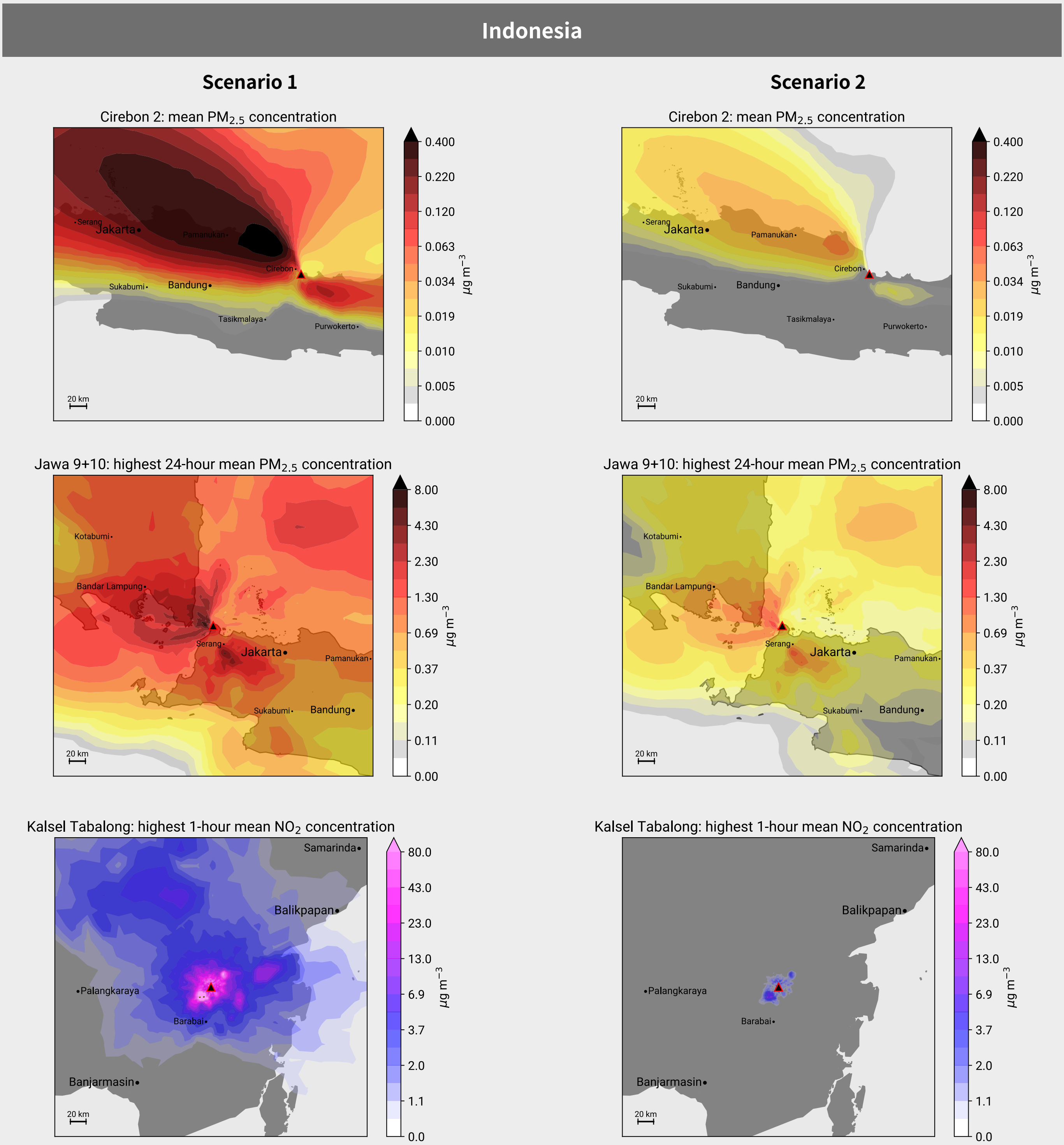


Figure 8. Modeled pollutant concentration from the Indonesian power plants (triangles). Cirebon-2 (top row), Jawa 9&10 (middle row) and Kalsel Tabalong (bottom row).
Left column: Scenario 1, right column: Scenario 2. Note that the color scales are logarithmic and different from one row to another.

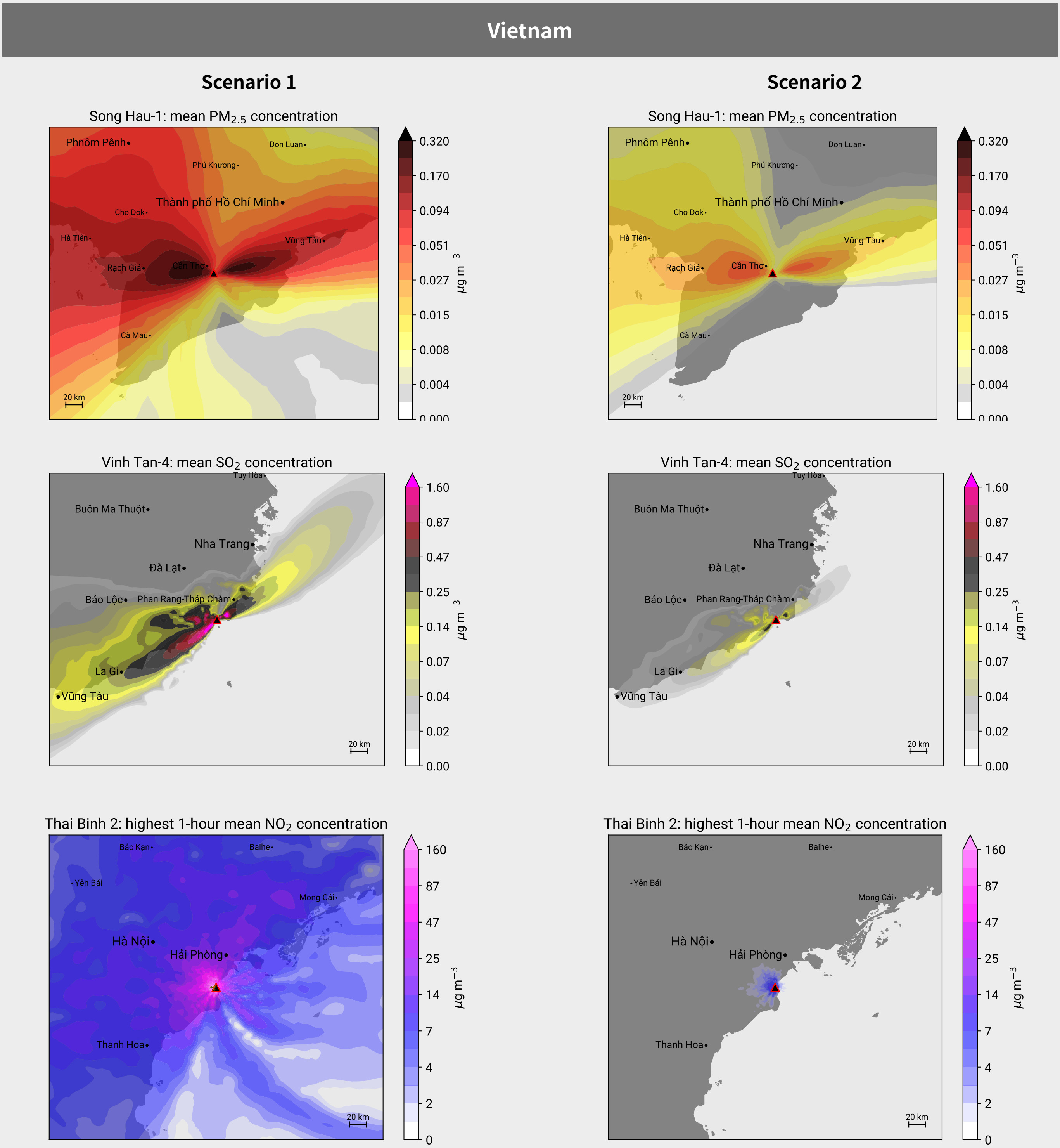


Figure 9. Modeled pollutant concentration from the Vietnamese power plants (triangles) Song Hau-1 (top row), Vinh Tan-4 (middle row) and Thai Binh-2 (bottom row).

Left column: Scenario 1, right column: Scenario 2. Note that the color scales are logarithmic.

Table 4.
Modeled maximum pollutant concentrations over different averaging intervals compared to WHO Air Quality Guidelines.

Pollutant	NO_2 (µg/m³)		SO_2 (µg/m³)				$PM_{2.5}$ (µg/m³)	
Averaging interval	1 hour		24 hours		10 minutes		24 hours	
Scenario	Sc. 1	Sc. 2	Sc. 1	Sc. 2	Sc. 1	Sc. 2	Sc. 1	Sc. 2
WHO guideline	200	200	20	20	500	500	25	25
Maheshkhali (BGD)	**1491**	82	**461.8**	**36.8**	**3848**	307	**35.5**	2.9
Jawa 9&10 (IDN)	241*	27	27.9*	8.2	328	97	8.0	1.9
Cirebon-2 (IDN)	220*	11	**25.4**	2.0	421	33	9.7	0.8
Kalsel Tabalong (IDN)	250*	9	**26.3**	2.3	313	27	4.1	0.3
Nam Dinh (VNM)	138	10	15.4	2.9	201	38	7.8	1.4
Nghi Son2 (VNM)	**400**	25	**32.4**	6.2	**698**	133	12.0	1.9
Song Hau-1 (VNM)	**245**	15	**31.0**	5.1	504*	83	8.0	1.2
Thai Binh-2 (VNM)	**407**	22	**34.7**	6.5	**569**	106	11.4	1.9
Vinh Tan-4 (VNM)	**364**	35	**83.1**	12.2	**726**	107	15.8	1.9
Vinh Tan-4 Exp. (VNM)	**311**	16	**37.2**	5.7	263	40	6.6	0.8

Figures in **bold red** indicate where WHO air pollution guidelines are modeled to be exceeded. The guideline exceedances marked by * occur only in unpopulated areas (ocean or unpopulated land).

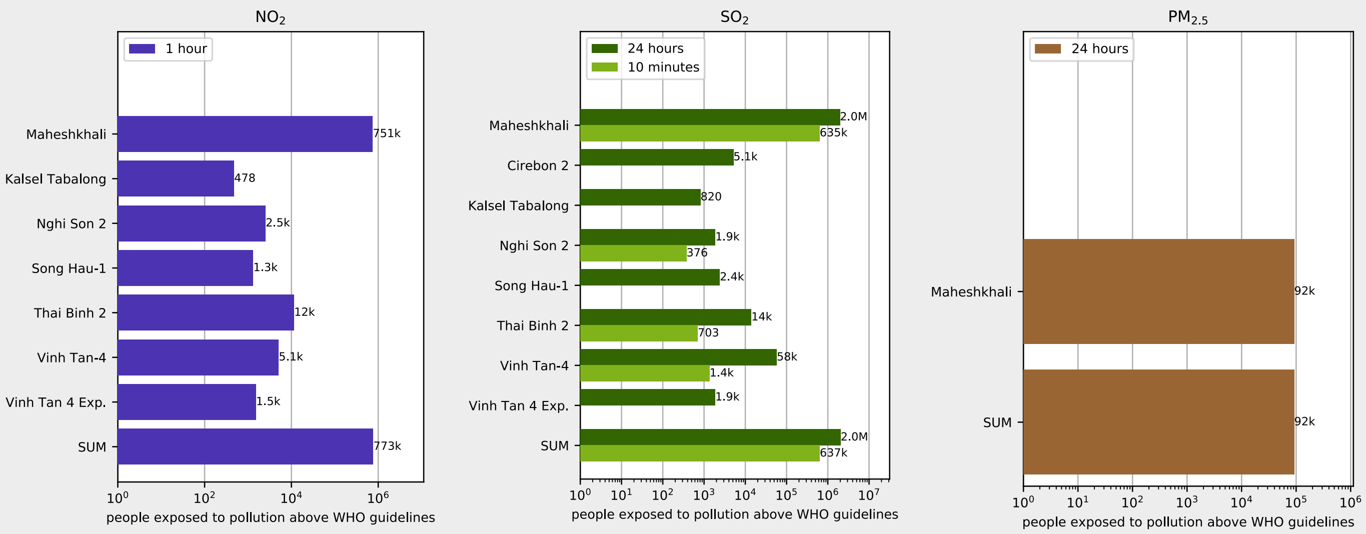


Figure 10. Modeled numbers of people exposed to pollution levels exceeding WHO air quality guidelines under Scenario 1.

In Scenario 2 (not shown), the only violation of WHO guidelines is modeled to occur against the 24-hour SO_2 guideline by the Maheshkhali CFPP, affecting 4 thousand people.[54]

Table 5.
Modeled total number of people exposed to pollutant concentrations above WHO guidelines for average air pollutant concentrations in different time intervals.[55]

Pollutant	NO_2		SO_2		$PM_{2.5}$	
Averaging interval	annual	1 hours	24 hours	10 minutes	annual	24 hours
Air Quality Guideline (µg/m³)	40	200	20	500	10	25
Exposure to above-guideline levels under Scenario 1		773 thousand people	1.96 million people	637 thousand people		92 thousand people
Exposure to above-guideline levels under Scenario 2			4 thousand people			

Impacts on human health

Exposure to air pollution carries a substantial risk of respiratory and other diseases, especially for vulnerable groups such as children, elderly people, and people with pre-existing respiratory ailments. Even pollutant concentrations below the WHO guidelines may be harmful. Applying a widely used health impact assessment method[56,57,58] (see Appendix) we modeled the number of annual premature deaths due to the pollution from the power plants that are financed by South Korean PFAs under both scenarios.

The results are shown in Tables 6-8 and Figure 11. Under Scenario 1 (actual emission limits), air pollutant emissions from the ten plants are projected to cause between 1,600 and 5,000 premature deaths each year, adding up to a total of 47,000 to 151,000 premature deaths over an expected 30-year lifespan of the power plants.[59]

Table 8 shows the projected premature deaths per year broken down by cause. Two thirds of the projected fatalities are due to $PM_{2.5}$ pollution, mainly by causing ischemic heart disease (IHD) and stroke.

According to the study, the most deadly plants are Maheshkhali in Bangladesh and Cirebon-2 in Indonesia, each projected to be responsible for between 400 and 1,200 premature deaths each year they operate (Tab. 6 and Fig. 11 top). Both plants are located such that over the course of a year, the pollution emitted by them spreads predominantly to a nearby large metropolitan area (Chittagong and Jakarta, respectively, Fig. 7 top left and Fig. 8 top left).

Vietnam is expected to be the most affected country, with six South Korean PFA-financed power plants and 38% of the modeled total premature deaths occurring there, followed by Indonesia (29%) and Bangladesh (20%) (Tab. 7 and Fig. 11 bottom).

The remaining 13% (between 206 and 664 premature deaths annually) are projected to occur in neighboring countries, namely China (81-246 premature deaths annually; 5.0% of total), India (45-132; 2.7%), Cambodia (31-115; 2.2%), Myanmar (31-104; 2.0%), Thailand (15-54; 1.0%), Laos (2-9; 0.2%) and Malaysia (2-6; 0.1%) who do not host any of the South Korean financed CFPPs included in this report, but are impacted by air pollutants from such plants in neighboring countries. Over the 30-year lifespan of the plants, this is projected to cause between 6,200 and 20,000 premature deaths in these countries (China: 2,400-7400 total premature deaths; India: 1,400-4,000; Cambodia: 920-3,400; Myanmar: 930-3,100; Thailand: 440-1,600; Laos: 63-258; Malaysia: 54-171).

The total premature death toll from the ten power plants could be reduced by more than 90% to 161-483 annual premature deaths if South Korean emission standards were applied (Scenario 2), which would save 1,400 to 4,500 lives each year and a total of 42,000 to 136,000 lives over the average 30-year lifetime of the power plants (Tab. 6)

Table 6.
Projected numbers of annual premature deaths caused by emissions from the studied power plants under Scenarios 1 and 2.

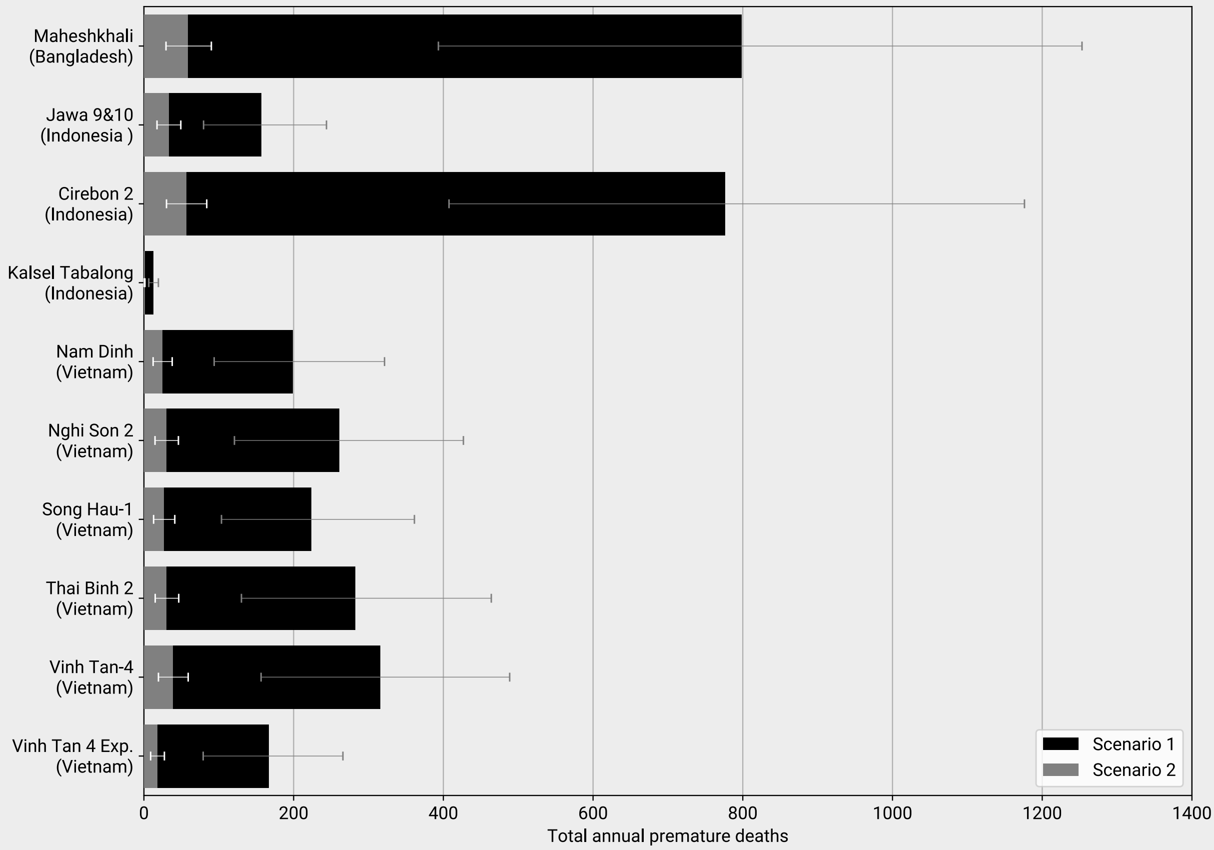
	Scenario 1 (actual emission limits)			Scenario 2 (South Korean emission standards)			Difference		
Plant	central estimate	low estimate	high estimate	central estimate	low estimate	high estimate	central estimate	low estimate	high estimate
Maheshkhali (BGD)	798	393	1,253	58	30	90	740	364	1,163
Jawa 9&10 (IDN)	157	80	244	33	18	49	124	62	195
Cirebon-2 (IDN)	776	408	1,176	56	30	84	720	377	1,092
Kalsel Tabalong (IDN)	13	7	19	1	1	1	12	6	18
Nam Dinh (VNM)	198	94	321	24	12	38	174	82	284
Nghi Son2 (VNM)	261	121	427	30	15	46	231	106	381
Song Hau-1 (VNM)	224	104	361	27	13	41	197	91	320
Thai Binh-2 (VNM)	282	130	464	30	15	47	252	115	418
Vinh Tan-4 (VNM)	315	157	489	39	19	59	277	137	430
Vinh Tan-4 Exp. (VNM)	166	79	266	18	9	27	149	70	239
Total (annual)	**3,190**	**1,572**	**5,021**	**315**	**161**	**483**	**2,875**	**1,410**	**4,538**
Total (30 years)	**95,700**	**47,148**	**150,615**	**9,456**	**4,836**	**14,481**	**86,244**	**42,312**	**136,140**

Table 7.
Projected numbers of annual premature deaths caused by emissions from the studied power plants under Scenarios 1 and 2 per country.[60]

	Scenario 1 (actual emission limits)			Scenario 2 (South Korean emission standards)			Difference		
Country	central estimate	low estimate	high estimate	central estimate	low estimate	high estimate	central estimate	low estimate	high estimate
Bangladesh	643	315	1,015	47	23	72	597	291	943
Cambodia	71	31	115	9	4	14	62	27	101
China	157	81	246	19	10	28	138	70	218
India	87	45	132	7	4	10	81	42	123
Indonesia	946	493	1,440	90	48	135	856	445	1,305
Laos	5	2	9	0	0	1	5	2	8
Malaysia	4	2	6	1	0	1	3	2	5
Myanmar	67	31	104	5	2	8	62	29	95
Thailand	33	15	54	4	2	7	29	13	47
Vietnam	1,177	553	1,900	134	67	208	1,042	486	1,692
Total	**3,189**	**1,566**	**5,020**	**315**	**161**	**483**	**2,874**	**1,406**	**4,537**

Table 8. Projected numbers of annual premature deaths broken down by cause of death.
See Figure A.2 (Appendix) for numbers of premature deaths caused by each of the power plants. COPD: Chronic obstructive pulmonary disease, LRI: Lower respiratory infections, IHD: Ischemic heart disease.

		Scenario 1 (actual emission limits)			Scenario 2 (South Korean emission standards)			Difference		
Pollutant	Cause	central estimate	low estimate	high estimate	central estimate	low estimate	high estimate	central estimate	low estimate	high estimate
$PM_{2.5}$	$PM_{2.5}$	197	115	278	22	13	31	175	102	247
	Lung cancer	149	59	238	19	8	30	130	52	208
	LRI	122	0	249	14	0	28	108	0	220
	Diabetes	111	14	209	13	2	24	99	12	185
	IHD	982	624	1,340	111	71	151	871	553	1,189
	Stroke	641	387	894	75	45	105	566	342	790
	Total	2,202	1,199	3,209	253	138	369	1,948	1,062	2,840
$PM_{2.5}$	All causes	988	372	1,812	62	23	114	926	349	1,698
Total		**3,190**	**1,571**	**5,021**	**315**	**161**	**483**	**2,875**	**1,410**	**4,538**



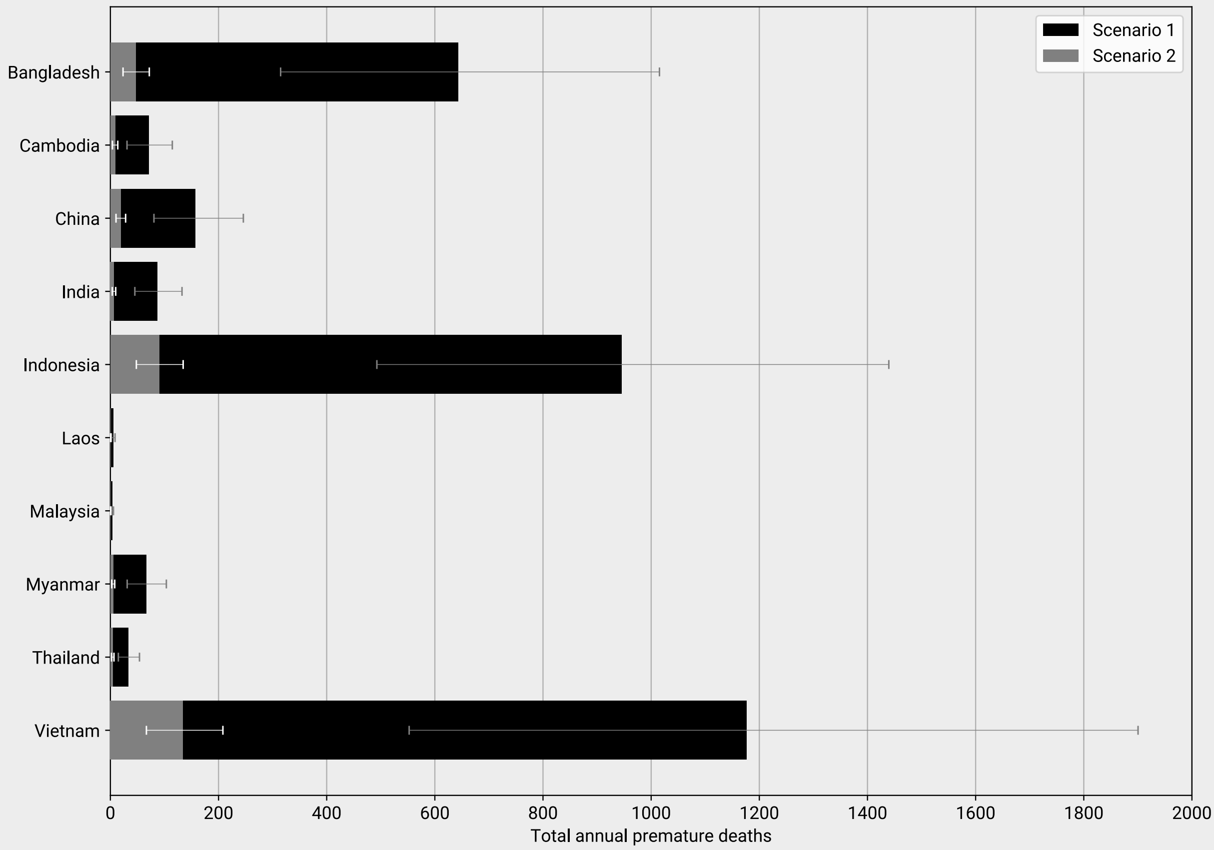


Figure 11. Total modeled number of annual premature deaths per power plant (top) and per country (bottom). Whisker lines show the 95% confidence interval.[61] (data from Tabs. 6 and 7)

Summary: The projected death toll of South Korea's double standard

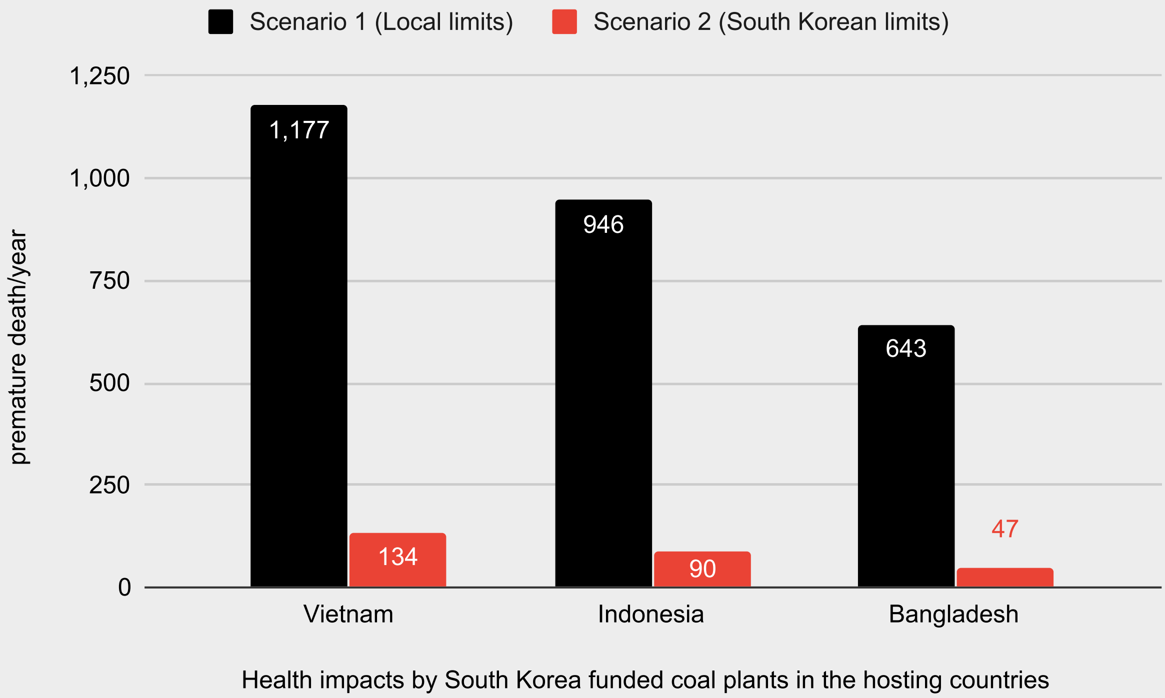


Figure 12. Number of modeled annual premature deaths due to South Korean PFA-financed coal power plants in host countries for Scenario 1 (black) and Scenario 2 (red). (Uncertainties are about 50%, see Tab. 7).

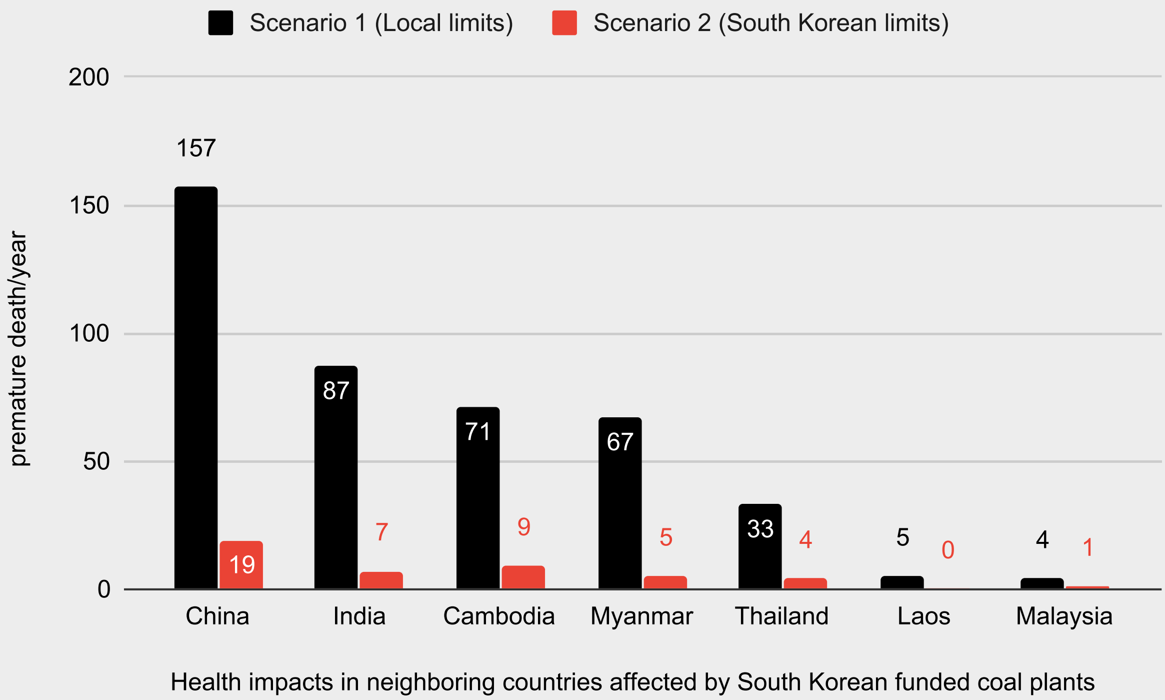


Figure 13. Number of modeled annual premature deaths in third-party countries (neighboring the host countries) due to South Korean PFA-financed coal power plants for Scenario 1 (black) and Scenario 2 (red). (Uncertainties are about 50%, see Tab. 7).

Greenpeace East Asia Seoul office has modeled the air quality and health impacts of overseas coal-fired power plants supported by South Korean PFA investment. It is estimated that the ten power plants operating at existing local emission limits (Scenario 1) will cause in total 3,200 (between 1,600 and 5,000)[62] premature deaths per year (Fig. 12), amounting to an expected 96,000 (47,000 to 151,000) premature deaths over the power plants' average 30-year lifespan. These figures do not take into account future population growth, which would further increase the premature death toll.

Furthermore, the model does not take into account background pollution from sources other than the power plants.[63] As this would add to the pollution from the power plants, it is likely that the actual number of people exposed to dangerous pollution levels, and the resulting premature death toll, are even higher.

The highest premature death tolls are projected to occur in Vietnam, followed by Indonesia and Bangladesh. Neighboring countries affected by cross-boundary pollution, namely China, India, Cambodia, Myanmar, Thailand, Laos and Malaysia, are modeled to suffer a total of 424 (206 to 664) premature deaths per year as a result of the emissions (Fig. 13).

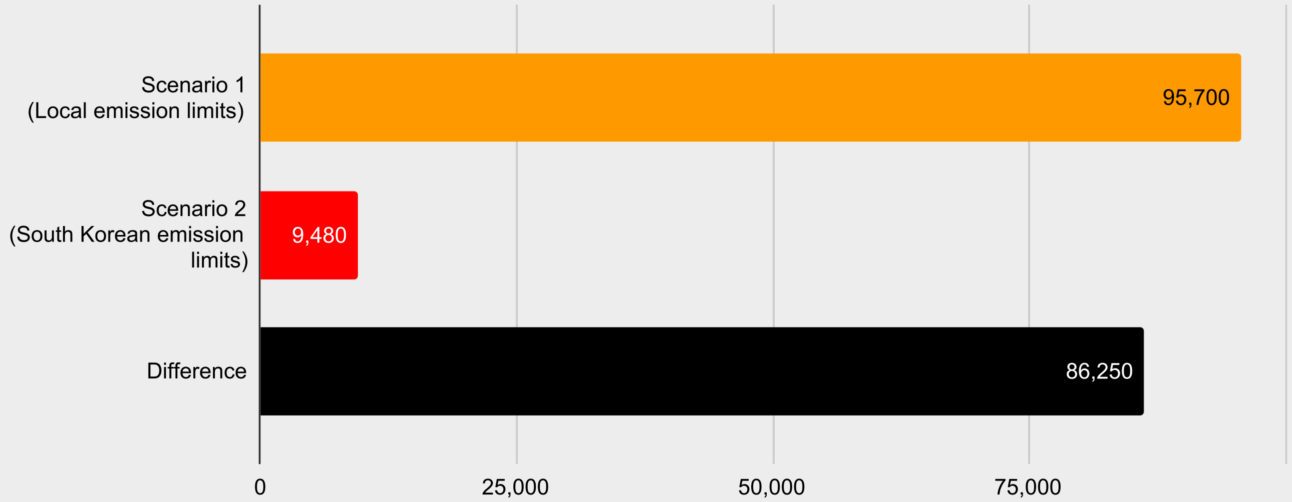


Figure 14. Modeled total premature deaths due to South Korean PFA-financed coal power plants over their 30-year average lifespans for Scenario 1 (local emission limits), Scenario 2 (South Korean emission standards) and the difference between the two.
(the premature deaths that would be prevented if the overseas coal power plants were required to meet South Korean limits) Uncertainty intervals are about 50% (not shown).

The power plants in these countries operate with emission limits that are considerably less stringent than those imposed in South Korea. If the double standard in emission limits was removed and all plants operated within South Korean emission standards, around 90% of these modeled annual premature deaths could be avoided. In total 86,000 (42,000 to 136,000) modeled premature deaths could be avoided if all 10 South Korean PFA-financed power plants operated to South Korean emission standards over their 30-year average operation time (Fig. 14).

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4. Even “advanced technology” coal plants are deadly

The coal industry and some power utilities have been claiming that advanced technology, like high efficiency boilers, would dramatically reduce pollution. The South Korean Government and the coal industry are promoting ultra-supercritical (USC) technology, claiming it will provide exceptional advances in environmental performance.[64] The technology, usually promoted as ‘clean coal’ technology, is leading some decision-makers and PFAs to mistakenly believe that by choosing USC technology for coal power plants, air pollutant and carbon dioxide emissions can be sufficiently mitigated. South Korea’s largest banks (KEXIM, K-SURE, KDB) have also endorsed the mythology of advanced technology.

Although these plants are more efficient than those using older technology, they are still significant polluters, even when strict emission limits are applied.

A coal-fired power plant equipped with a USC boiler can reduce air pollutant emissions by approximately 10-15% compared to a power plant with a sub-critical boiler. (Figure 15). In contrast, wind, solar PV, solar thermal power, geothermal, hydropower and other renewable energy technologies do not emit any air pollutants during operation. The only way to eliminate the hundreds of thousands of deaths associated with air pollution from coal burning is to phase out these dirty power plants in favor of clean and modern renewable energy sources.

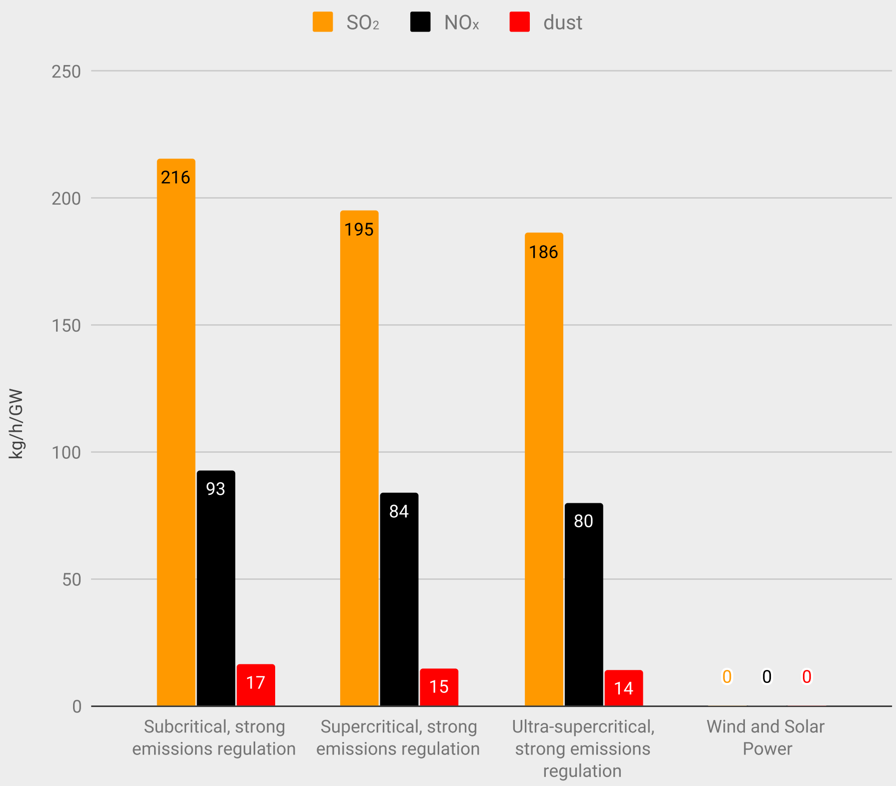

Figure 15.
Air pollutant (SO_2, NO_x, dust) emissions per produced electric energy from different types of coal-fired power plants[65] vs. renewable energy plants during operation (unit: kg/h/GW).

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5. South Korea's public finance agencies would save lives by supporting renewable energy, not coal

This report highlights the unethical and deadly double standard being applied by the South Korean public finance agencies. It documents how South Korean PFAs (KEXIM, K-SURE and KDB) fund CFPPs constructed abroad that apply poorer emission limits than those in South Korean domestic plants. It shows that South Korean financiers are complicit with the CFPP industry in profiting from unnecessary illness and premature deaths.

There can be no justification for developing projects overseas that do not follow the environmental protections and health standards required at home in South Korea. To address this unethical double standard, **the South Korean Government must immediately stop KEXIM, K-Sure and KDB from investing in overseas projects in the power, industrial and other sectors if their emissions limits do not meet South Korea's own emission standards.** At the same time, the governments in the host countries of the coal projects described in this report should protect their citizens' right to a safe and healthy environment, by significantly strengthening their emission standards for already existing coal power plants.

These findings underline the huge health impact of coal combustion for electricity generation, and show that even when CFPPs emissions are tightly regulated, the industry still causes widespread incidence of serious illness and premature death. There is no method available to make the CFPP industry safe or clean.

Not discussed here is the additional burden created by the emission of greenhouse gases from CFPPs which inflicts long-term damage to humans and the environment on a global scale through ocean acidification, global warming and many other ways, including associated secondary effects such as sea level rise, mass-loss of biodiversity, intensification of extreme weather events and so on.

We therefore conclude that the South Korean financiers, KEXIM, K-Sure and KDB, as well as all host countries, must immediately cease all CFPP projects and divert their investments into renewable alternatives. Countries must work together towards a clean, carbon-neutral economy, and South Korea should play a leadership role in doing so.

With the support of South Korea and the international community, governments in the host countries of the coal projects described in this report must undertake an energy transition from coal to renewable energy.

This change in policies and investments must be accelerated now, to protect human and environmental health, and to safeguard the future of our planet. Renewable energy and measures to increase energy efficiency are rapidly becoming cheaper and more competitive[66] than building new coal-fired power plants, and rather than exacerbating air pollution and climate change, they provide a solution.

We therefore conclude that the South Korean financiers, KEXIM, K-Sure and KDB, as well as all host countries, must immediately cease all CFPP projects and divert their investments into renewable alternatives. Countries must work together towards a clean, carbon-neutral economy, and South Korea should play a leadership role in doing so.

By ending this deadly double standard, hundreds of thousands of lives could be saved by South Korea's PFAs. By ending all coal combustion for electricity generation we can save countless more.

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Peer Reviewer Profile

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Christopher A. James

Former Environmental Protection Agency (EPA) regulator and state air quality director

Christopher A. James advises regulators and advocates on how to reduce greenhouse gases and toxic pollutants to meet existing and new air quality standards, improve water quality, and protect consumers. His projects span the areas of air quality, energy efficiency, distributed resources, demand response, and linking energy and the environment in air quality and energy planning processes.

Recent projects include working with environmental advocates and health professionals in Eastern Europe and Southeast Asia to improve emission standards for power plants. Mr. James has also worked with Chinese air quality officials since 2008 to develop and implement plans to improve air quality, strengthen China's air law and develop a comprehensive environmental permitting system.

Mr. James has 35 years experience working on air quality, covering nearly every facet of this topic, from developing ambient monitoring networks, emissions inventories and control measures, to implementing and enforcing such measures. He champions multi-pollutant air quality planning and qualifying energy efficiency as both a reliability resource and air quality control measures.

Mr. James was director of air planning and manager of climate change and energy programs for the Connecticut Department of Environmental Protection (DEP), where he served as staff lead for the state's participation in the Regional Greenhouse Gas Initiative. He was also the DEP representative to the Connecticut Energy Conservation Management Board, which provided advice and oversight to utility energy efficiency programs.

At the Seattle regional office of the EPA he received two "gold medals" for his efforts to enforce air quality regulations. He also worked in the private sector for Synapse Energy Economics and for consultants to the utility and biomass energy industries.

He holds a bachelor's degree in mechanical engineering from Worcester Polytech and a master's degree in environmental studies from Brown University.

Glossary of technical terms and acronyms

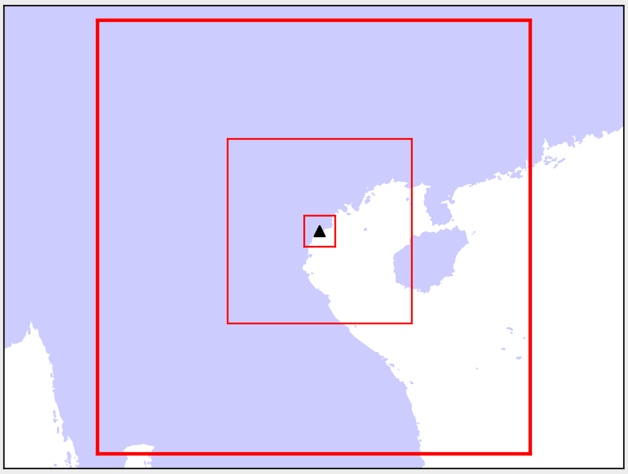
PFA	public finance agency
public finance agency	Finance agency owned by the national government. In this report, it largely refers to the following three institutions of the South Korean Government. - Official export credit agency: **Export-Import Bank of Korea (KEXIM), Korea Trade Insurance Corporation (K-SURE)** - State owned policy development bank: **Korea Development Bank (KDB)**
WHO	World Health Organization
air quality guideline	A guideline for the pollutant concentration, issued by the WHO. Pollutant concentrations above the guideline value are deemed to be harmful to human health. For levels below guideline concentrations, it is not clear whether, or to what extent, human health is put at risk.
CFPP	coal-fired power plant
exceedance	A period of time when the concentration of an air pollutant is greater than the appropriate WHO air quality guideline.
confidence interval	Our health assessment model uses empirical data such as population numbers, background death rates and others. The true values of these variables are not known with infinite precision. This implies that no model study can give results with absolute certainty. Instead, we provide a range (interval), which most likely contains the true value. In this work, we use the 95% confidence interval. That means that with 95% probability, reality is somewhere inside the confidence interval and with 5% chance it is actually outside this interval (above or below). The value which has the highest probability to be the true value is called the central estimate. It is somewhere inside the confidence interval. The bounds of the confidence interval are called low and high estimate **Synonyms:** 95%-confidence interval (in this work), "between x and y"
central estimate	see confidence interval
low estimate	see confidence interval
high estimate	see confidence interval
emission concentration	The actual concentration of some pollutant in the flue gas of a power plant (e. g. 425 mg/Nm^3 or 200 ppm). It can be above the emission limit for this power plant (i. e. breaking some law) or below (i. e. complying with the law). Unlike the pollutant concentration, it is measured inside the flue gas and not at ground level outside the power plant. **Related (but not synonym):** emission rate **Not to be confused with:** pollutant concentration
emission rate	The amount of a pollutant that is emitted per unit time by a specific power plant (e. g. 100 kg/hour). In some cases, this is used instead of the emission concentration as a measure of how polluting the coal-fired power plant is. **Related (but not synonym):** emission concentration
emission limit	The maximum allowed emission concentration (or sometimes emission rate) for a specific plant. It can be prescribed by national standards, environmental permit conditions (which can be based on national standard but can also be looser or stricter) or some other legal regulation. **Related (but not synonym):** emission standard
emission standard	A nationally (or super-nationally) regulated maximum limit on emission concentration (or sometimes emission rate). It may be distinct from the emission limit of a specific plant, which can differ from the national standard. **Related (but not synonym):** emission limit
air pollutant	An unwanted substance found in the air in the form of a solid particle, a liquid droplet or a gas. The substance may be hazardous, harmful to human health if inhaled or damaging to the environment. Prominent examples are $PM_{2.5}$, the NO_x group and SO_2. **Synonym (here):** pollutant
pollutant concentration	The actual concentration of some pollutant at any location (close to or far away from a power plant). This is the concentration that the local population is exposed to, which means that the impact on public health is determined by this value. The pollutant concentration can be above and the air quality guideline (i. e. violating it) or below (i. e. complying with it). **Not to be confused with:** emission concentration

maximum 24-hour concentration	The highest measured or modeled pollutant concentration, when averaging over 24-hour periods. This is not a regulation or a guideline, but an event that really occurs (or is modeled to occur). Correspondingly for other time periods (1 hour, 10 minutes). **Not to be confused with:** air quality guideline, emission limit
flue gas	The gas that exits the power plant via its stacks.
subcritical	Conventional coal-fired power plants operate at boiler conditions that are physically described as subcritical. The water used by the generator to drive the turbine is boiled to generate steam which drives the turbines. The turbine water is not elevated to supercritical temperature and pressure. Subcritical CFPPs have a thermal efficiency of <35% Note: In this context, the term critical does not indicate a “crisis” or an “out-of-control point”, as is does in every-day language. **Related (but not synonym):** supercritical, ultra-supercritical
supercritical	When operating at supercritical conditions, the boiler water is at temperature and pressure so high that it assumes an exotic physical state: it is no longer distinguishable whether it is a gas or a liquid. Supercritical coal-fired power plants achieve higher thermal efficiency by operating at pressures of 22-25 MPa and temperatures of 540-580°C. Supercritical CFPPs have a thermal efficiency of 35-40%. **Related (but not synonym):** subcritical, ultra-supercritical
ultra-super-critical	Ultra-supercritical coal-fired power plants operate at even higher temperatures than supercritical plants. They achieve higher thermal efficiency by operating at pressures of 22-25 MPa and temperatures of 580-620°C. Ultra-supercritical CFPPs have a thermal efficiency of 45-52%. **Related (but not synonym):** subcritical, supercritical
MPa	Megapascal (unit of pressure). The pressure of the atmosphere is 0.1 MPa.
NO	Nitrogen monoxide. A trace gas that is produced in all combustion processes. It converts from and to NO_2. **Synonym:** nitric oxide
NO_2	Nitrogen dioxide. A trace gas that is produced in all combustion processes. It converts from and to NO. The amount of NO_2 in the atmosphere is commonly used as a proxy to assess the health impact of the whole NO_x group.
NO_x	Nitrogen oxides. A generic term for NO and NO_2, a group of trace gases that are harmful to human health.
SO_2	Sulfur dioxide. Sulfur dioxide is a trace gas produced by industrial processing of materials that contain sulfur, including coal burning in power plants and processing of some mineral ores. About 99% of the sulfur dioxide in air comes from human sources. Sulfur dioxide reacts with other substances to form harmful compounds, such as sulfuric acid (H_2SO_4), sulfurous acid (H_2SO_3) and sulfate particles and it is therefore a cause of acid rain and particulate matter pollution (→ $PM_{2.5}$).
dust	Solid airborne particles. In CFPP flue gas, this is mainly fly ash. A subclass of dust is $PM_{2.5}$.
$PM_{2.5}$	Fine particulate matter. Solid particles with aerodynamic diameter of less than 2.5µm (i. e. small dust particles).[67] They are so small that they can pass from the lungs into the bloodstream, affecting the entire cardiovascular system and causing a range of health impacts. Due to their small size, the particles stay airborne for a long time and can travel hundreds or thousands of kilometers. Fossil fuel combustion emits $PM_{2.5}$ directly, as fly ash and other unburned particles, and contributes to $PM_{2.5}$ indirectly through emissions of gaseous pollutants (particularly SO_2 and NO_x) which form $PM_{2.5}$ in the atmosphere. $PM_{2.5}$ is harmful to human health and thus an air pollutant.
mg	Milligram. A thousandth of a gram. (about the mass of a small ant)
mg/Nm^3	Milligram per normalised cubic meter. The mass of a substance in milligrams, in one cubic meter of a gas. Gases expand or contract greatly with changing temperature and pressure. The flue gas of a power plant is much hotter than normal ambient temperature at the Earth’s surface. To make the pollutant concentration inside the flue gas comparable, units are converted to what its concentration would be under temperature and pressure that is normal at the Earth’s surface.
ppm	Parts per million. A description of concentration: the number of parts out of 1 million that are a certain substance. Can refer to mass or volume.
µg	Microgram. A millionth of a gram. (about the mass of an ant’s antennae)
µm	Micrometer. A thousandth of a millimeter.

Appendix. Methodology of Health Impacts Modeling

Method overview

The impacts of the CFPPs are derived using a combined approach that uses an atmospheric dispersion modeling 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 simulate the propagation of the power plant emissions into the environment.

a) **Meteorology model.** The meteorology around the power plant is modeled using version 3 of the The Air Pollution Model (TAPM).[68] 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 each CFPP or cluster of closely located power plants. 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 (Fig. A.1). Boundary conditions are derived from the GASP model of the Australian Bureau of Meteorology.[69] 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 chemistry-transport model simulation.

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 mode.[70] 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.[71] 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.

Figure A.1.
For each power plant, a numerical weather model with three nested domains (red boxes) around the source (black triangle, here Nam Dinh in northern Vietnam) is run.

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 proponents of each CFPP project. The following data was collected from environmental impact assessments, environmental permits, feasibility studies and other documents related to each CFPP project, when available:

- Annual emissions volumes (AEV)
- Emissions rates at full operation (ER)
- Pollutant concentrations in flue gas (CFG)
- Flue gas volume flow (FGV)
- Plant net thermal efficiency (EFF), electric capacity (CAP) and steam condition (subcritical/supercritical/ultra-supercritical)
- Projected plant load factor (PLF)
- Coal type
- Stack height and inner diameter
- Flue gas release temperature and velocity
- Stack location

To assess both short-term maximum air quality impact and annual pollutant exposure and health impact, data on both AEV and ER is required. When either AEV or ER was unavailable, the missing parameter was calculated from

$$ER = AEV / PLF,$$

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

$$ER = FGV * CFG.$$

When FGV was unavailable, it was estimated as:

$$FGV = CAP / EFF * SFGV,$$

where SFGV is specific flue gas volume per unit thermal input (Nm^3/GJ) estimated for the type of coal used by the power plant. When project-specific CFG information was unavailable, the plant was assumed to follow national emission standards in the country.

To estimate 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 project documents when available, and otherwise from closest corresponding samples in the USGS World Coal Quality Inventory.[72] Average values for Kalimantan coal were used for projects importing unspecified seaborne sub-bituminous coal; average values for Australian coal were used for projects importing unspecified seaborne bituminous coal, and averages for Sumatran coal for projects using unspecified domestic seaborne coal in Indonesia.

Once AEV and ER were obtained for all projects, 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 the maximum short-term air quality impact. For the purposes of health impact assessment, the average concentrations were scaled down by the plant's projected load factor, effectively spreading the plant's annual emissions volume evenly through the year.

When data on coal type and plant location were not disclosed, these data were taken from the Global Coal Plant Tracker.[73] For stack height and inner diameter, flue gas release temperature and velocity, EFF and PLF, the median value for comparable projects was used to fill in missing data. When specific information on thermal efficiency was not provided but the plant steam condition was known, net thermal efficiency of 38%, 41% and 44% was assumed for subcritical, supercritical and ultra-supercritical plants, respectively.

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 mx is the mortality (number of deaths per number of inhabitants) under the increased pollution Δx, and m0 is the mortality in absence of the excess pollution. In state-of-the-art epidemiological models, r depends exponentially on x for $m_x \ll 1$:[74,75]

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

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).[76]
- **Country boundaries** are taken as defined in version 3.6 (May 2018) of the GADM project.[77]
- **Concentration response factors (CRFs).** We used the CRFs listed in Table A.1. CRFs have been computed from relative risks given in WHO (2013)[78] for NO_2, Pope et al. (2015)[79] for $PM_{2.5}$-diabetes, Mehta et al. (2011)[80] for $PM_{2.5}$-lower respiratory infections and Krewski et al. (2009)[81] for all other $PM_{2.5}$. The same values are used for all countries and all age groups.[82]
  - Elimination of double-counting effects: Up to 33% of the NO_2-caused deaths may overlap with cases due to $PM_{2.5}$ exposure.[83] To account for possible double counting when summing death numbers from different causes, we modified the raw number of NO_2-caused deaths after applying the CRFs:
    - we reduced the lower bound 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 adjusted in this way.

- **Background mortality** is taken from the IHME Global Burden of Disease Study 2017.[84] The data set provides values per death cause per country. The numbers for the countries and causes in this report are listed in Table A.2.

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

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).

	NO_2		$PM_{2.5}$[85]	
	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[86,87]	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.2.
Background death rates for the countries 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.

	All	LRI	LC	COPD	Diabetes	Stroke
Bangladesh	5652 (5198-6138)	245 (209-294)	161 (139-186)	412 (366-468)	159 (134-187)	1030 (933-1138)
Cambodia	6318 (5823-6893)	612 (541-694)	139 (117-165)	189 (159-220)	93 (76-109)	866 (784-969)
China	7400 (7187-7619)	127 (119-155)	490 (468-510)	684 (655-757)	78 (74-83)	1494 (1446-1547)
India	7178 (7049-7311)	368 (333-389)	61 (57-65)	694 (574-779)	135 (121-147)	526 (496-551)
Indonesia	6363 (6090-6661)	170 (154-181)	144 (124-168)	259 (221-291)	236 (209-265)	1195 (1125-1271)
Laos	6536 (5934-7222)	539 (437-664)	124 (100-150)	236 (190-287)	108 (88-132)	849 (736-969)
Malaysia	5389 (5041-5772)	773 (513-884)	154 (133-176)	157 (136-203)	48 (43-54)	579 (526-638)
Myanmar	7765 (7060-8435)	428 (372-482)	155 (136-174)	736 (508-872)	314 (262-373)	673 (600-737)
Thailand	6616 (6086-7129)	512 (329-595)	276 (246-311)	225 (198-276)	166 (146-194)	610 (551-685)
Vietnam	6306 (5801-6932)	189 (164-234)	370 (317-432)	294 (249-338)	177 (152-205)	1161 (1060-1293)

Table A.3.
Translation dictionary between death cause names in the CRF sources and in the background death rate data (highlighting where translation does not fully match).

CRF	Background death rate
All causes (all)	All causes
Lower respiratory infections (LRI)	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

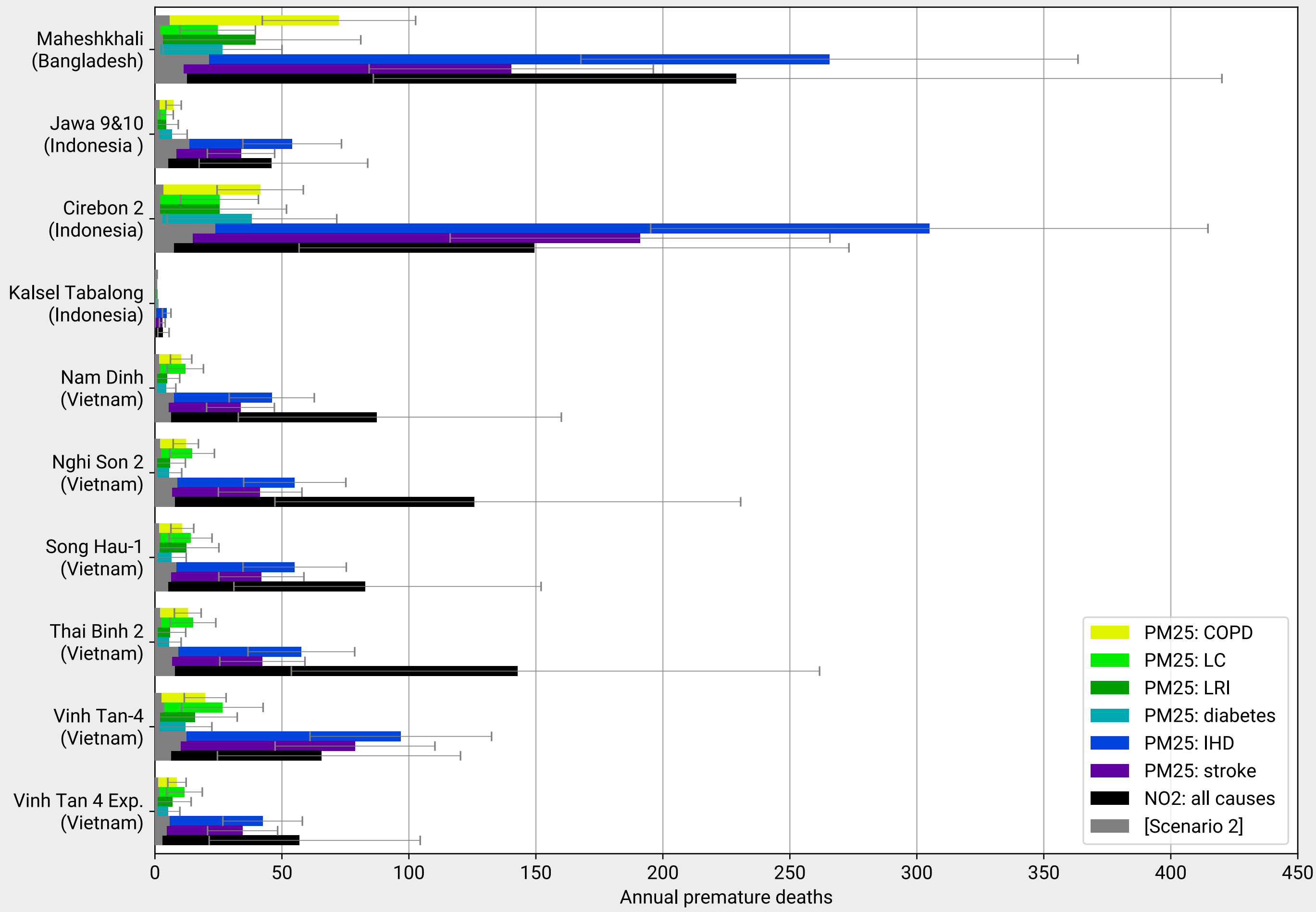


Figure A.2.

Modeled number of premature deaths due to pollution of each power plant broken down by cause of death for Scenario 1 (colored and black bars) and Scenario 2 (grey bars). Whisker lines show 95% confidence intervals for Scenario 1.

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59. In these projections, future population growth has not been taken into account, which would further increase the number of premature deaths caused.

60. Differences in the total numbers with respect to Tables 6 and 8 arise from a small portion of the computed deaths (mostly fractional) which occur in countries that are not listed here, and from rounding errors.

61. Errors are not independent between the two scenarios: If the lower value is true for Scenario 1, then also for Scenario 2 the lower value is true - and vice versa.

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85. 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.

86. Up to 33% of these cases may overlap with cases due to $PM_{2.5}$ exposure.

87. 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 (Double standard: How Japan's financing of highly polluting overseas coal plants endangers public health, Greenpeace Southeast Asia, August 20, 2019). This lead to a slight underestimation of the lower bound of the death number.

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