Trends in mercury emissions from coal-fired power plants dashboard – Methodology

Globally, coal combustion is the second largest source of mercury emissions. The GEF-funded project **"Assessment of Existing and Future Emissions Reduction from the Coal Sector Toward the Implementation of the Minamata and Stockholm Conventions"** aims to address this issue. This dashboard provides an overview of coal-fired power plants worldwide and explores potential future scenarios for reducing mercury and CO2 emissions.

1. Rationale for target country selection

China remains the most dependent on coal but balances this with significant advancements in emission reduction – lessons can be learned by other countries on prioritising energy efficiency (closing less efficient plants) and installing advanced air pollution control devices (APCD) systems.

In **India**, coal provides just under 50% of the country's total energy production and just over 70% of its electricity. India has plans to reduce its dependence on coal, but there are still over 30 GW of units in construction and 36 GW in the planning stage.

Coal provides just over 60% of **Indonesia's** electricity. Over 80% of coal plants in operation are younger than 10 years old, implying a long potential phase-out path.

Vietnam has significant renewable energy (including hydropower) but still relies on fossil fuels for around 43% of its energy capacity. Total capacity continues to grow and will reach 146 GW by 2030.

Coal provided 60% of the power generation in the **Philippines** in 2022. As with many other Southeast Asian countries, investment in coal has been significant over the past decade, and, subject to completion of approvals and permits, new plant build could continue until 2030.

Pakistan and **Bangladesh** have been included because of plans to significantly increase the installed capacity of the coal-fired power plants (CFPP) fleets. Although these two countries make a relatively minor global contribution to CFPP-related emissions, a significant proposed expansion of coal-fired capacity is indicated.

For **South Africa**, the challenges are largely economic and technical. Coal is critical to the country's grid, also showing the highest deposit of mercury in the coal resource globally. However, the fleet has been in decline for years, with plant failures becoming more frequent. But without any alternative power sources, the coal fleet will remain essential.

If China and India are excluded, Southeast Asian countries, mainly **Indonesia**, **Vietnam**, **Malaysia**, the **Philippines**, and **Thailand**, account for around 50% of the CO_2 emissions in the entire Asian continent. Moreover, for many of the focus countries having a relatively young coal-fired power plants (CFPP) fleet, especially China, Indonesia, and Vietnam, the young age of the coal fleet means that an outlook of plants retiring even 10 or 15 years early, will not result in significant results for decades yet. Further, for these young fleets, early retirement is economically challenging for plants that rely on decades of operation to achieve their return on investment.

2. Methodologies and assumptions

This project used publicly available data and information to analyse potential future emissions from coal-fired power plants (CFPPs) in target countries, based on the different future energy sectors and policy-based assumptions. To do this, it was necessary to adopt strict and repeatable methodologies and to apply sensible and appropriate assumptions. The sections below outline this process, and the decisions made.

a. *Assumptions for future CFPP profiling*

The status of existing and future (commissioned or under construction) CFPPs on a global- and country-specific level was taken from the Global Energy Monitor's Global Coal Plant Tracker (GCPT) database (Coal Plant Tracker Database, Global Energy Monitor; https://globalenergymonitor.org/projects/global-coal-plant-tracker/). The database includes plant/unit-specific information such as capacity (MW), location, furnace conditions (subcritical, supercritical, ultra-supercritical, circulating fluidized bed boiler), operation status (operating, construction, pre-construction, shelved, retired, mothballed), year of commissioning, expected year of retirement, and annual/lifetime CO2 emissions. The database version that was used for the additional mercury emission and projection scenarios was updated in January 2024. Country-specific scenarios and mercury emission predictions up to 2050 were built from the database with the addition of country- or plant-specific information generated from government databases, scientific literature and/or reports from various open-access reports of consultancy agencies.

b. *Business-as-usual scenario (BAU)*

This scenario predicts emissions of pollutants from national CFPP fleets under the assumption that all existing (operating) CFPPs will continue to operate for the full period of their remaining design lifetime. Where unit-specific information was not available on the remaining plant lifetime, a default 40-year life expectancy was used – commencing from the day of the unit installation year.

The CFPP projects listed as "under construction" were expected to be commissioned or operational by the year 2025, if not indicated otherwise on the GEM database, and are assumed to continue to also operate for a default 40-year design lifetime.

All CFPP projects in a pre-construction phase (announced, permitted, and pre-permitted) are assumed to be commissioned by 2030 at the latest, if not indicated otherwise on the GEM database, and it is assumed that they will also continue to operate for a 40-year design lifetime.

Within the BAU scenario, there are two separate scenarios:

- **BAU-1** considers the remaining lifetime of currently operating plants and assumes that only projects under construction will continue.
- **BAU-2** considers the remaining lifetime of currently operating plants and assumes that all projects under construction and also under pre-construction will continue.

c. *Plant-specific mercury emission estimates*

Mercury emission estimates were calculated for each CFPP unit listed on the GEM database using assumptions on coal consumption rates (1000 tons/year), installed air pollution control devices (APCDs), mercury input factor for the feed coal (mg/kg), and the mercury retention factor according to the installed APCDs. The default mercury retention factors according to different APCD configurations were sourced from the UNEP toolkit (Level 2; Table 5-6) and expressed in the following equation:

$$\text{Hg emission (kg/yr)} = CC * IF * (100 - RF)/100$$

Where:

CC coal consumption (in 1000 tonnes/year),
IF mercury input factor of the feed coal (in mg/kg)
RF mercury retention factor (%) according to the CFPP unit's APCD configuration.

A relatively high degree of uncertainty in the mercury emission estimates is unavoidable due to plant-specific variations in their installed APCD configurations, mercury input factors from the feed coal (e.g., import/domestic coal blending, coal washing practices, co-combustion with biomass/ammonia, etc.), and the mercury retention rates that can be impacted by several factors apart from the stated APCD configurations that are installed.

Moreover, a report by the Basel and Stockholm Convention Regional Centre for Southeast Asia (BCRS-SEA, 2017) highlights discrepancies between calculated and reported mercury retention factors for APCDs. This indicates potential underestimation of mercury emissions reduction achieved by APCDs compared to reported values in the UNEP Toolkit.

Given these complexities, country-specific scenarios are imperative to accommodate variations in CFPP operation and APCD configurations. Consequently, the current global emissions estimate should be viewed as a semi-quantitative measure of future emissions reduction in the coal sector.

d) Country-specific capacity factors used in the project

The capacity factor of a coal-fired power plant (CFPP) is a measure of how often the plant operates at its maximum output over a specific period, typically expressed as a percentage or rate. It is calculated by considering the actual energy output of the plant over a given period by the maximum possible output if the plant operated at full capacity during that time.

Considering this definition, a 100% capacity factor assumes that the CFPP operates at a maximum power output all throughout the year. This is improbable in a real-world scenario due to various factors influencing the plant's operation, such as planned maintenance or unplanned outages of the units that reduce unit operating hours, the unit's combustion technology and age, the *in praesenti* power demand and level of other power generation resources, and interruptions in fuel supply and quality to name a few.

For this reason, the project is conscious that a 100% capacity factor for all CFPP units within a selected country is improbable but still showcase a maximum coal consumption estimate - and subsequent emissions forecast - that a country is capable to reach from its entire CFPP fleet. However, notable fluctuations in CFPP capacity factors among the focus countries are recorded - even more so, having substantial capacity factors fluctuations within each country on a unit scale. However, the current database considered a default focus country capacity factor estimate as an average over its entire CFPP fleet, with these estimates shown in Table 1 below supported by other literature sources where available.

Table 1: Default focus country capacity factors that were used for coal consumption estimates at a unit level within the modified emissions database* used in this project.

Country	Capacity factor	Reference
China	0.48	IEA World Energy Ooutlook report of 2023 - Table B.4; Zhang et al., 2022
India	0.65	IEA World Energy Ooutlook report of 2023 - Table B.4
Indonesia	0.78	Indonesia Comprehensive Investment and Policy Plan (CIPP) report
Vietnam	0.70	Breu et al., 2019
Thailand	0.75	Energy Policy and Planning Office of Ministry of Energy, Energy Statistics
Malaysia	0.53	Global average - IEA 2023 World Energy Outlook
Philippines	0.67	Philippines Department of Energy (DOE) report
South Africa	0.53	Global average - IEA World Energy Ooutlook report of 2023 - Table B.4
Pakistan	0.53	Global average - IEA World Energy Ooutlook report of 2023 - Table B.4
Bangladesh	0.39	Bangladesh Power Development Board, Annual Report 2015-16, 2016

* The baseline metadata for the estimation of CFPP unit coal consumption, including unit heat rate values (Btu/kWh) and design capacity (MW) was obtained from the Global Energy Monitor Global Coal Plant Tracker database (January 2024 update; https://globalenergymonitor.org/projects/global-coal-plant-tracker/).

3. Summary of Air Pollution Control Devices (APCDs)

a. Particulate matter (PM) control in flue gas

i. Fabric filtration (FF)

Fabric filters (FF), also known as baghouses, are designed to remove particulate matter (PM) from flue gas by passing them through a tightly woven or felted fabric. As the gas flows through the fabric, particulate matter is trapped on the surface, forming a filter cake that enhances collection efficiency. Periodic cleaning (e.g., by shaking or reverse air pulses) removes the accumulated particles from the fabric.

ii. Electrostatic Precipitators (ESP)

Electrostatic precipitators (ESPs) are air pollution control devices that remove particulate matter (PM) from flue gas. They work by charging particles in the gas stream using a high-voltage electric field. The charged particles are then attracted to oppositely charged collection plates, where they accumulate and are periodically removed. This process allows for the removal of fine particulates, such as dust, ash, and other solid or liquid aerosols, from exhaust gases.

iii. Co-benefit to CO2 and mercury emission control

By removing fine particulates, both FFs and ESPs improve the efficiency of downstream air pollution control systems that also serve as a co-benefit towards capturing CO_2. Cleaner gas streams improve overall performance and reduce energy demands of these systems, which indirectly could lead to the lowering of CO_2 emissions from these systems.

Since mercury is often associated with fine particulates, PM control technologies capture these particulates, and consequently, mercury. Moreover, improved gas stream quality supports more efficient functioning of subsequent control technologies that either target mercury reduction directly, or those providing a co-benefit to reduce mercury from flue gas.

b. Sulfur control in flue gas

i. Flue gas desulfurization (FGD)

Flue Gas Desulfurization (FGD) systems are air pollution control devices designed to remove sulfur dioxide (SO_2) from the flue gases of coal-fired power plants. They typically use an alkaline reagent, such as limestone or lime, to chemically react with SO_2 in a scrubbing process. The reaction forms solid or liquid byproducts, such as gypsum, which can be removed and potentially repurposed.

Two main types of FGD technologies are used: Wet-FGD uses a liquid reagent (e.g., limestone slurry) to scrub SO_2 from flue gases and produces a wet byproduct, often gypsum, which can be repurposed. Dry-FGD Uses a dry or semi-dry reagent (e.g., lime or sodium bicarbonate) in a spray dryer or reactor to neutralize SOx and produces a dry byproduct that is typically disposed of or recycled.

ii. Co-benefit to CO2 and mercury emission control

FGD systems improve the overall efficiency of emissions control by preparing cleaner flue gases for carbon capture systems (e.g., amine-based CO_2 scrubbers). This results in better performance and energy savings, indirectly reducing CO_2 emissions. Some advanced FGD systems are designed to capture CO_2 alongside SO_2, though this is less common in conventional setups. For this reason, FGD systems play a critical role in reducing SO_2 emissions while also supporting the performance of integrated pollution control systems, leading to co-benefits in reducing CO_2 and mercury emissions in coal-fired power plants.

Mercury emissions, particularly in oxidized forms, tend to bind to fine particles or react with the byproducts of FGD processes, allowing for co-removal of mercury along with SO_2. Wet FGD systems, in particular, are effective at capturing water-soluble mercury species (e.g., mercuric chloride), contributing to reduced mercury release into the atmosphere.

c. Nitrogen control in flue gas

i. Selective catalytic reduction (SCR)

Selective Catalytic Reduction (SCR) is an air pollution control device designed to reduce nitrogen oxides (NO_x) emissions from flue gases. It works by injecting a reducing agent, typically ammonia (NH_3) or urea, into the flue gas stream, which reacts with NO_x over a catalyst (e.g., vanadium, titanium, or zeolites) to form harmless nitrogen (N_2) and water (H_2O).

ii. Co-benefit to CO2 and mercury emission control

SCR enhances combustion efficiency by allowing for optimized boiler operations, indirectly reducing CO_2 emissions per unit of energy produced. Cleaner flue gases from reduced NO_x can improve downstream CO_2 capture technologies, reducing energy costs and increasing capture efficiency.

SCR systems promote the oxidation of elemental mercury (Hg^0) to oxidized mercury (Hg^{2+}), which is more easily captured by flue gas desulfurization (FGD) or particulate control systems like fabric filters (FF). This synergistic effect enhances overall mercury capture and reduces its release into the environment.